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NOISE AND VIBRATION IN MINES
RESEARCH REPORTS 1972-1986

edited by G. Knight ***traduit par N.R Billette***

Volume 2 MRL 88–117 (R)

MICROMEDIA

Energy, Mines and Resources Canada
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CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

NOISE AND VIBRATION IN MINES RESEARCH REPORTS: 1972-1986. VOLUME 2—HEARING PROTECTION–EAR MUFFS

BRUIT ET VIBRATION DANS MINES 1972-1986. RAPPORTS DE RECHERCHE PROTECTION DE L'OUÏE–SUPRA-AURICULAIRES

Edited by G. KNIGHT
Canadian Mine Technology Laboratory

Traduit par N.R. Billette
Laboratoire canadien de technologie minière

MARCH 1988

MARS 1988

MINING RESEARCH LABORATORIES
DIVISIONAL REPORT MRL 88–117 (R)

LABORATOIRES DE RECHERCHE MINIÈRE
RAPPORT DE DIVISION LRM 88–117 (R)

FOREWORD

The compendium of CANMET reports on noise measurement equipment, noise assessments in mines and hearing protection assessments is a tribute to the dedication, hard work and professional expertise of Mr Savich in his field of research specialization. The research contained within the reports was accomplished by Mr. Savich or under his direction in the relatively brief period of 1972 to 1986 while working as a research scientist at the Elliot Lake Laboratory.

It is hoped that this compendium of reports on research carried out while at CANMET will be useful to those interested in finding solutions to the problems caused by miner exposure to noise and vibration.

J.E. Udd
Director
Mining Research Laboratories

AVANT-PROPOS

Le recueil de rapports de CANMET sur les instruments de mesure du bruit, les évaluations du bruit dans les mines et la protection de l'ouïe constitue un hommage à l'assiduité, le professionnalisme et l'expertise de M. Savich dans son champ de spécialisation en recherche. La recherche relatée dans ces divers rapports fut accomplie par M. Savich lui-même, ou sous sa direction, au cours de la courte période allant de 1972 à 1986, alors qu'il oeuvrait en tant que chercheur scientifique au laboratoire d'Elliot Lake.

Les Laboratoires de recherche minière de CANMET espèrent que ce recueil de rapports de recherche serviront à tous les intervenants du milieu intéressés aux problèmes reliés à l'exposition des mineurs au bruit et aux vibrations.

Directeur
Laboratoires de recherche minière
J.E. Udd

NOISE AND VIBRATION IN MINES — RESEARCH REPORTS: CANMET/ MINING RESEARCH LABORATORIES, 1972-1986.

Reprinted in 6 Volumes

Edited by

G. Knight*

French translations by

N.R. Billette*

ABSTRACT

This compendium is a reprint of all the reports on noise and vibration research undertaken by CANMET. Most of the studies were undertaken in cooperation with mines across Canada, mainly mines located in Ontario and on several occasions with the Mines Accident Prevention Association of Ontario. Two studies were carried out through the awarding of contracts.

The compendium is in 6 volumes, two of which are in parts, as follows;

1. Vol. 1–Glossary, Introduction, and Measurement Methods.
2. Vol. 2–Hearing Protection—Ear Muffs.
3. Vol. 3–Mine Noise Surveys–Part A.
4. Vol. 3–Mine Noise Surveys–Part B.
5. Vol. 3–Mine Noise Surveys–Part C.
6. Vol. 4–Mill and Surface Plant Noise Surveys–Part A.
7. Vol. 4–Mill and Surface Plant Noise Surveys–Part B.
8. Vol. 5–Noise Abatement Studies.
9. Vol. 6–Vibration Studies and General(includes unclassified)

Within each volume or section the reports are listed chronologically. The glossary has been removed from 3 of the reports and listed separately at the front. The introduction describes the main features of the contained studies in each volume.

KEYWORDS: Noise, vibration, mine surveys, noise control,
hearing protection, bibliography.

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BRUIT ET VIBRATION DANS LES MINES - RAPPORTS DE RECHERCHE: LABORATOIRES DE RECHERCHE MINIÈRE DU CANMET, 1972-1986.

Réimpression (en anglais) dans 6 Volumes

édité par G. Knight*

traduit par N.R. Billette*

RÉSUMÉ

Ce recueil constitue une réimpression de tous les rapports concernant la recherche sur le bruit et les vibrations exécutée à CANMET. La plupart des travaux ont été entrepris en collaboration avec des mines canadiennes, principalement avec des mines situées en Ontario et, en de nombreuses occasions, avec l'assistance de l'Association de prévention des accidents miniers en Ontario (MAPAO). Deux recherches furent réalisées en tant que contrats.

Le recueil comprend 6 volumes, dont deux comprenant plus d'une partie, répartis comme ceci:

1. Vol. 1–Glossaire, introduction et techniques de mesure.
2. Vol. 2–Protection de l'ouïe - protecteurs supra-auriculaires.
3. Vol. 3–Relevés de bruits de mines–partie A.
4. Vol. 3–Relevés de bruits de mines–partie B.
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6. Vol. 4–Relevés de bruits d'usines et d'ateliers de surface–partie A.
7. Vol. 4–Relevés de bruits d'usines et d'ateliers de surface–partie B.
8. Vol. 5–Études de réduction du bruit.
9. Vol. 6–Études des vibrations et divers.

Dans chaque volume ou section, les rapports sont classés en ordre chronologique. Le glossaire (en anglais seulement) provient de l'amalgamation de termes contenus dans trois des rapports et a été regroupé séparément au début. L'introduction décrit les principaux éléments des travaux contenus dans chaque volume.

MOTS-CLÉS: bruit, vibration, relevé en mine, contrôle du bruit, protection auriculaire, bibliographie.

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INTRODUCTION

This research was undertaken because noise-induced hearing loss is a substantial problem in the mining industry and because vibration-induced damage occurs to blood capillaries in the hands of miners, particularly drillers. Noise-induced hearing loss generally occurs over a long period of time. Because humans are adaptable and tend to compensate for the gradual loss, the impairment goes unrecognized for a long time. Exposure to very loud noises, such as explosions, can give rise to immediate and disabling damage to the hearing system.

Hearing impairment affects both employees and employers. Compensation payments are becoming substantial. The hearing loss can only be detected in the early stages by frequent checks of hearing acuity and this is now required for miners in most Canadian jurisdictions.

Noise is measured as the peak to trough pressure difference in the vibration waves in air. The results are expressed in relative terms to the hearing sensitivity of (young adult) humans in good health using a logarithmic scale to the base 10. Thus, an increase of one Bel is equivalent to a ten times stronger noise level. However, the Bel is a large unit and it is more convenient to use a unit ten times smaller, the decibel. Hearing acuity is frequency dependent. It peaks at a frequency of about 1 000 Hertz (cycles per second) and falls off to the extreme limits, roughly 20 and 20 000 Hz. Sound measurement equipment is much less frequency dependent and a weighting factor is used to relate it to human hearing. The "A"-scale is used in hearing loss programs generally. Thus, the weighted noise level in decibels is usually abbreviated as dBA. Hearing loss is believed to occur when exposure is above a threshold level, 85 dBA and 90 dBA have been specified in various jurisdictions. The hearing loss is proportional to the height of the noise excursion and its duration. Three factors are in use for equating the potential hearing loss to the noise level:

1. A doubling every 3 dBA–The equal energy principle, used in many hearing loss control recommendations.
2. A doubling every 4 dBA–used in one or more recommendations.
3. A doubling every 5 dBA–used in the principal USA legislation: the Occupational Safety and Health Act (OSHA).

Canadian regulations are set provincially and federally: either factor 1 or 3 is used.

In addition to potential hearing losses high noise levels lead to problems in safety, fatigue and communication.

Most of the noise studies have been directed at surveys of noise in mines and the efficacy of hearing protection measures. The mine surveys have shown that many miners are exposed to noise levels above the threshhold for potential hearing loss and that immediate hearing protection is required as well as an effort to reduce the noise level of mining machinery.

This compendium is a reprint of all the reports on noise and vibration research undertaken by CANMET. Most of the studies were undertaken in cooperation with mines across Canada, mainly mines located in Ontario and, on several occasions, with the Mines Accident Prevention Association of Ontario. Two studies were carried out through the awarding of contracts. A few of the early reports by Miron Savich were based on his MSc. thesis work undertaken at the Institute of Mineral Research of McGill University, situated at Mont St. Hilaire, Quebec.

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Within each volume or section the reports are listed chronologically. The glossary has been removed from 3 of the reports and amalgamated. It is presented separately at the front, following the contents table.

The noise measurement methods used are described in some reports in the first volume as well as being described in many of the other reports on surveys etc.. Five main classes of noise measurement techniques have been used in the noise surveys. These are:

1. Hand-held meters with "A"-scale weighting and slow response time averaging over a short period of time, a second or less, with manual recording. This was used in the earlier surveys and occasionally later. A graphical method of determining the average noise level for the survey is given in report 75–71.
2. The hand-held sound level meter was also used in the peak measurement mode for studies of impulse, or short duration, noise as in report 84–83.

3. A shift length recording system in which the average noise level over a period, such as a minute, is stored on a memory bank and read out later. In the system used, the results were read at the end of the shift and analysed using a computer program as described in report 78–62.

4. The noise dosimeter averages noise level over a short period of time and, if it exceeds the threshhold, adds it up using an appropriate factor to give the noise level as a ratio of the exceedance to permissible for the shift. The instrument usually has an indicator for showing whether the noise level has exceeded the ceiling level of 115dBA promulgated in the OSHA regulations (presumably intended for unprotected ears). This instrument has been used in many surveys and tests on hearing protectors. One unit was described and tested in report 76–83.

5. Frequency analysis sound level meter. This determines the sound level in each band of frequency of significance, usually one third octave wide. The equipment is desirable because the attenuation of noise by any barrier is frequency dependent and because the frequency of an offensive sound may be very helpful in determining its source. Ear muffs are sound attenuators and therefore frequency dependent, they are not as good attenuators at low frequencies as at high frequencies.

Ear muffs (hearing protectors) were shown to be highly efficient in laboratory tests providing attenuations of 31 to 44 dBA at frequencies of 1 000 Hz and above. Safety glass-frames passing under the seal of the ear muff, however, were found to reduce attenuations to 25 to 34 dBA. The wearing of safety glasses is obligatory in most working places in the mining industry. Field studies in mines showed that the effective protection factors for ear muffs could be less than 10 dBA. The surveys carried out at Falconbridge Mines Ltd., Reports 86–58, 86–59, 86–60, 86–61 with a final summary in 86–88 illustrate the value of such studies. The attenuations of ear muffs found in mines are shown in Figure 1, where the measured attenuation(OSHA basis) in dBA is shown plotted against the mean sound level in dBA (variously described in the reports as $L_{eq}(60s)$; L_{OSHA} or $L_{Avg.}$). The required attenuation line is drawn assuming that the average sound levels persist for a full 8 hour shift and that ear plugs are not worn. This figure suggests that about half of the population examined were not protected to the extent required. However, neither of these assumptions are true and it is probable that substantially more than the half of the population was protected to the extent required. The major reason for the poor performance of ear muffs in practise was found to be poor fitting, the spring clamping force was often inadequate, particularly on small headed individuals. Emphasis was placed on the measurement and control of clamping force and the need to fit earmuff supports to head size. On the basis of these surveys recommendations were made to improve control of hearing protection programs.

The noise surveys are a useful repository of information. The detailed surveys, using the data logging technique, which form the major part of volumes 3 and 4, provide invaluable information to those planning noise control programs in many mining operations. Nearly 700 man-days were logged in the detailed surveys. It could be seen that the distribution of noise exposure during the shift varies from nearly constant to highly variable. In the mines 262 shifts out of the 432 recorded were worked at sound levels above permissible exposure. The highest values were about 40 times greater requiring hearing protection of at least 28 dBA attenuation. This would be even higher if the proposed OSHA standards instead of the existing rules (at the time the reports were written) were used as the basis for assessment. In the mills and surface plants only 13 out of the 250 shifts recorded were worked at sound levels above permissible exposure. The highest value required about 10 dBA attenuation in the hearing protection.

Noise control studies have been carried out with respect to light and medium weight percussion rockdrills, diamond drills and diesel engine exhaust systems. The diamond drill studies point out the need for a thorough investigation of all the noise sources, four major sources have been identified. Reduction of only one source would, as a result, produce almost no effect on sound level, a reduction of about 1 dBA. It may, however, modify the sound quality significantly.

The high noise levels measured in mining emphasize the requirement for substantial work to control noise on mining machinery. It is likely that eventually it will be desirable not to expose men to sound levels over 85 dBA and that the necessity for hearing protection will be considered an undesirable working condition to be eliminated.

The contract study on vibration found that stopers and jackleg drills subjected miner's hands to vibration levels sufficient to induce vibration white finger disease in periods of one to four years in over half the population. It was also shown that vibration isolators could be effective in substantially reducing vibration transmission to hands and proposed that vibration isolation handles should be developed and used on percussion drills. Some sites where whole-body exposure to vibration exceeded guidelines were found in surface plant and mills. Underground diesel powered vehicles were not examined.

The report 73–17 in the miscellaneous section in volume 6 is a good exposition of the noise and vibration problems in mines. The topics covered include noise and vibration measurement; noise and vibration exposure standards; and noise and vibration sources; as well as control methods.

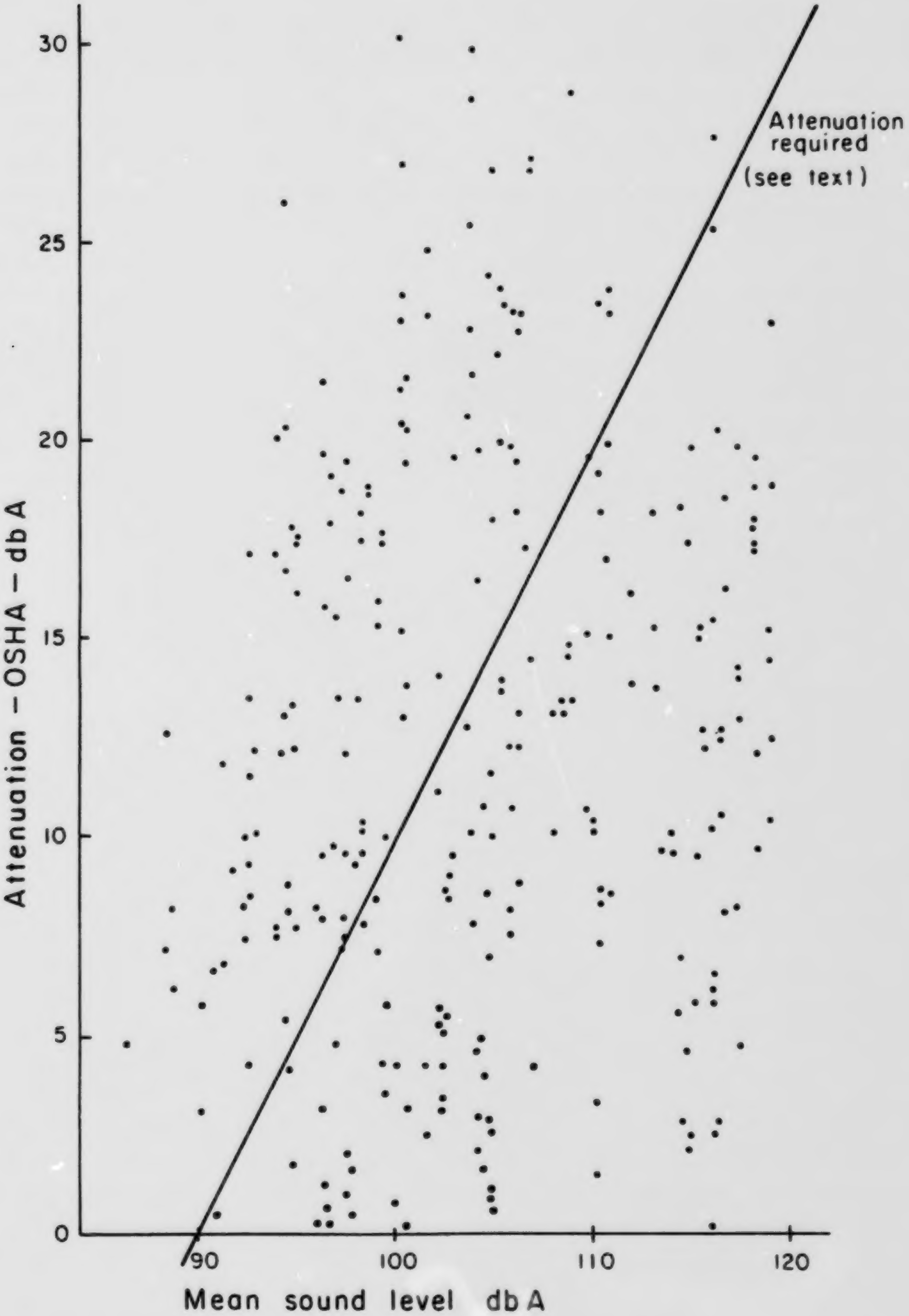

Fig. 1–The attenuation of ear muffs measured in use in mines.

Fig. 1–L'atténuation des protecteurs supra-auriculaires en usage dans le mines

It should be appreciated that many of the reports cover more than one topic and that they have not been cross-referenced. They are entered in the category corresponding to the major aspect studied.

The report pages have not been renumbered. To assist in locating each report red coloured pages are used to separate them. Each of these has page and report numbers in the top right hand corner and the full title and description of the report and its publication details, if other than a divisional report.

The reports are in their original language, usually english. The abstracts have been translated into french and are given at the front of each report.

ACKNOWLEDGEMENTS

The editor wishes to thank his colleagues in the Mining Research Laboratories for assistance in gathering and compiling these reports.

INTRODUCTION

Ces travaux de recherche ont été entrepris parce que la perte auditive due au bruit constitue un problème important dans l'industrie minière, ainsi qu'à cause des dommages aux capillaires sanguins induits par vibration aux mains des mineurs, et plus particulièrement des foreurs. La perte auditive due au bruit découle d'une exposition prolongée. Puisque les humains s'adaptent facilement et tendent à compenser la perte graduelle, la détérioration passe longtemps inaperçue. Toutefois, l'exposition à de très grands bruits, une explosion par exemple, peut entraîner un dommage immédiat incapacitant du système auditif.

La perte auditive affecte tant l'employeur que l'employé. Les paiements compensateurs sont devenus substantiels. Les premiers signes de dégradation de l'ouïe ne sont reconnus qu'au prix de multiples vérifications de l'acuité auditive, ce qui est maintenant exigé dans la plupart des juridictions canadiennes concernant les mineurs.

Le bruit est mesuré comme différence entre le sommet et le creux des ondes vibratoires dans l'air. Les résultats sont exprimés en termes relatifs à la sensitivité auditive d'un humain (jeune adulte) en bonne santé, en utilisant une échelle logarithme de base 10. Ainsi, une augmentation du niveau sonore d'un Bel équivaut à décupler l'énergie acoustique. Toutefois, le Bel constitue une unité représentant une somme énergétique importante, de sorte qu'il est plus approprié d'utiliser le décibel, une unité dix fois plus petite. L'acuité auditive dépend de la fréquence de l'onde. Elle atteint son maximum aux alentours de la fréquence de 1,000 Hertz (cycles par seconde) et diminue aux deux extrémités du spectre, soit 20 et 20,000 Hz respectivement. L'équipement de mesure du son est beaucoup moins dépendant de la fréquence utilisée, de sorte qu'un facteur de pondération est nécessaire pour relier le niveau sonore à l'acuité auditive humaine. L'échelle "A" est généralement utilisée dans les programmes de perte auditive. Dans ce cas, le niveau sonore pondéré est habituellement abrégé à dBA. La perte auditive est considérée se produire au-delà d'un seuil, 85 dBA et 90 dBA étant la norme dans diverses réglementations. La perte auditive est proportionnelle à la puissance de l'onde sonore et à la durée de l'exposition. Trois facteurs légaux sont utilisés pour établir la relation entre dommage potentiel et niveau sonore:

1. Le dommage double tous les 3 dBA – le principe d'énergie équivalente, à la base de nombreuses recommendations du contrôle de la perte auditive.
2. Le dommage double tous les 4 dBA – utilisé dans une recommendation ou plus.
3. Le dommage double tous les 5 dBA – en usage dans la principàles législation américaine, l'Acte de santé et sécurité occupationnelles (OSHA).

Les réglementations canadiennes sont émises aux niveaux provinciaux et fédéral: elles utilisent le facteur 1 ou le facteur 3.

En plus des pertes auditives potentielles, les niveaux sonores élevés entraînent des problèmes de sécurité, de fatigue et de communications.

La plupart des travaux sur le bruit ont été orientés vers des relevés du bruit dans les mines et vers l'appréciation de l'efficacité des mesures de protection de l'ouïe. Les relevés dans les mines ont démontré que plusieurs mineurs sont exposés à des niveaux sonores supérieurs au seuil de dommage auditif potentiel et qu'une protection immédiate de l'ouïe est nécessaire en parallèle à l'implantation de mesures de réduction du bruit de l'équipement et matériel minier.

Ce recueil incorpore tous les rapports de recherche sur le bruit et les vibrations réalisés par CANMET. La plupart des travaux ont été réalisés en collaboration avec des mines canadiennes, principalement avec des mines situées en Ontario et, à maintes reprises, avec l'assistance de l'Association de prévention des accidents miniers en Ontario (MAPAO). Deux recherches furent réalisées sur une base contractuelle. Quelques uns des premiers rapports de Miron Savich étaient basés sur sa thèse de maîtrise réalisée à l'Institut de Recherche minérale de l'Université McGill, situé à St-Hilaire, Québec.

Le recueil comprend six volumes, dont deux en plusieurs parties, comme suit:

1. Vol. 1–Glossaire, introduction et techniques de mesure.
2. Vol. 2–Protection de l'ouïe - protecteurs supra-auriculaires.
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Dans chaque volume ou section, les rapports sont classés en ordre chronologique. Le glossaire (en anglais seulement) provient de l'amalgamation de termes contenus dans trois des rapports. Il est présentement à part au début, tout de suite après la table des matières.

Les techniques de mesure du bruit utilisées sont décrites dans quelques rapports du premier volume, ainsi que dans de nombreux autres reliés aux relevés de mines, usines et ateliers. Cinq classes principales de techniques de mesure du bruit ont été expériementées dans les relevés sonores. Ce sont:

1. Des appareils manuels pondérant les fréquences selon l'échelle "A", avec un temps de réponse assez lent et le calcul de la valeur moyenne sur une brève période, une seconde ou moins, et enregistrement manuel du résultat. Il s'agit de la technique utilisée lors des premiers relevés, puis occasionnellement par la suite. Une méthode graphique pour déterminer le niveau acoustique pondéré au cours du relevé est expliquée dans le rapporté 75-71.
2. Le sonomètre manuel a aussi été utilisé en mode de mesure des bruits d'impact pour des études d'impulsion, ou bruit de courte durée, comme dans le rapport 84-83.
3. Un système d'enregistrement pour la période de travail (8 heures), qui cumule le bruit moyen d'une période de courte durée, une minute par exemple, et la conserve en mémoire pour lecture ultérieure. Le système utilisé permettait la lecture de l'information à la fin de la période de travail et son traitement ultérieur informatisé, tel que décrit dans le rapport 78-62.
4. L'audio-dosimètre calcule le niveau sonore moyen sur une courte période de temps et, surtout s'il excède le niveau légal, calcule le rapport du niveau sonore obtenu au niveau permis pour la période de travail. L'instrument possède également un voyant lumineux qui indique un dépassement de la limite légale absolue de 115 dBA promulguée dans les règlements OSHA (sans aucun doute pour une ouïe sans protecteur). Cet instrument a été utilisé dans plusieurs relevés et lors de tests concernant les protecteurs auriculaires. Un tel appareil a été décrit et vérifié dans le rapport 76-83.
5. Le sonomètre d'analyse fréquentielle. Cet instrument mesure le niveau acoustique moyen dans chaque bande de fréquence significative, habituellement de la largeur d'un tiers d'octave. L'instrument est nettement recommandable, puisque l'atténuation du bruit par toute barrière est fonction de la fréquence et parce que la fréquence d'un son agresseur contribue à localiser sa source. Les protecteurs auriculaires sont des atténuateurs de son et, de ce fait, dépendent de la fréquence d'émission. Ils n'atténuent pas les basses fréquences avec autant de bonheur que les hautes fréquences.

Les protecteurs supra-auriculaires ont démontré des habiletés d'atténuation allant de 31 à 44 dBA en laboratoire pour les fréquences de 1,000 Hz et plus. Les montures de lunettes de sécurité passées sous les coussins du protecteur réduisent cependant la protection qui passe alors de 25 à 34 dBA. Comme le port de lunettes protectrices est obligatoire pour la plupart des postes de travail dans l'industrie minière, des études sur le terrain dans les mines ont démontré que la protection réelle obtenue par des protecteurs supra-auriculaires peut ne pas dépasser 10 dBA. Les relevés effectués à Falconbridge Ltée, rapports 86-58, 86-59, 86-60, 86-61 avec un résumé final dans 86-88, illustrent la validité de tels travaux. La figure 1 (voir page 5) illustre l'atténuation en dBA (base OSHA) des protecteurs supra-auriculaires en usage dans les mines, où cette dernière est comparée au niveau acoustique pondéré en dBA (décrit différemment dans les rapports comme $L_{eq}(60s)$; L_{OSHA} ou $L_{Avg.}$). La ligne d'atténuation requise est illustrée en assumant que les niveaux acoustiques moyens persistent tout au long de la période de 8 heures et que des bouchons d'oreilles ne sont pas utilisés. Cette figure suggère que la moitié de la population des mineurs n'est pas protégée au niveau légal requis. Toutefois, aucune de ces deux hypothèses n'est vraie et il est fort probable qu'une proportion largement supérieure à la moitié se trouve protégée au niveau requis. La principale raison de la faible performance des protecteurs supra-auriculaires en pratique découle d'un mauvais ajustement, la force du ressort étant souvent inadéquate, principalement chez les individus ayant un faible tour de tête. L'emphase a été mise sur la mesure et le contrôle de la force de serre et le besoin d'ajuster les supports des protecteurs au tour de tête. Des recommendations basées sur ces relevés ont donc été faites, afin d'améliorer les programmes de contrôle pour la protection de l'ouïe.

Les relevés sonores constituent un recueil d'informations. Les relevés détaillés, utilisant la technique d'enregistrement des données, constituent l'essentiel des volumes 3 et 4, et contiennent de l'information précieuse pour tous ceux qui entreprennent des programmes de contrôle du bruit dans des opérations minières. Près de 700 jours-hommes ont été enregistrés lors des relevés détaillés. Il est ainsi possible de constater que la distribution d'exposition des mineurs au bruit varie, au cours de la période de travail, de presque constante à très variable. Dans les mines, 262 des 432 périodes de travail enregistrées l'ont été à l'aide de l'audio-dosimètre en niveau relatif à l'exposition permise. Les valeurs les plus fortes indiquaient un dépassement du seuil de 40 fois, signifiant une protection de l'ouïe de l'ordre de 28 dBA d'atténuation. Cette atténuation serait encore supérieure si les nouveaux standards proposés par OSHA étaient utilisés comme base au lieu des règles actuelles (au moment où les rapports étaient rédigés). Dans les usines et ateliers de surface, seulement 13 des 250 périodes de travail enregistrées l'ont été à l'aide de l'audio-sonomètre. La valeur la plus forte requerrait une atténuation de l'ordre de 10 dBA pour assurer la protection légale de l'ouïe.

Les travaux de contrôle du bruit ont été entrepris sur des foreuses à percussion de poids léger à moyen, sur les foreuses à diamant et sur les systèmes d'échappement des moteurs diesels. Les études sur les foreuses à diamant ont démontré un besoin d'investigation approfondie de toutes les sources de bruit, quatre sources majeures ayant été identifiées. La réduction d'une seule source résulterait en une atténuation à peine discernable du niveau acoustique moyen, à savoir 1 dBA. Elle pourrait cependant modifier la qualité sonore de façon appréciable.

Les niveaux sonores élevés mesurés dans les mines mettent l'emphase sur le besoin de travaux importants, afin de réduire le bruit du matériel minier. Il est probable qu'il faudra éventuellement limiter l'exposition des travailleurs à des bruits n'excédant pas 85 dBA et que l'usage de protecteurs auriculaires devienne une condition de travail indésirable, à éliminer.

L'étude contractuelle sur les vibrations a démontré que les foreuses manuelles verticales et sur béquille exposaient le mineur à des niveaux vibratoires suffisants pour induire le phénomène de Raynaud (insensibilité de la main) chez plus de la moitié de la population sur une période allant de 1 à 4 ans. Elle a aussi permis de démontrer que les isolants vibratoires permettent de réduire la transmission des vibrations à la main et suggéré de développer des poignées isolant les vibrations et de les adapter aux foreuses à percussion. Ces relevés ont aussi identifié des sites où les vibrations corporelles excédaient les directives dans les usines et ateliers de surface. Les véhicles souterrains à moteur diesel ne furent pas examinés.

Le rapport 73-17, dans la section "divers" du volume 6 expose bien les problèmes de bruit et vibrations dans les mines. Les sujets abordés sont la mesure du bruit et des vibrations, les standards d'exposition au bruit et aux vibrations, les sources de bruit et de vibrations, et les méthodes de contrôle.

Il faut enfin mentionner que plusieurs des rapports couvrent plus d'un sujet et qu'ils n'ont pas de renvoi mutuel. Ils sont inclus dans le manuel qui correspond au principal aspect étudié.

Les pages des rapports n'ont pas été renumérotées. Pour mieux localiser chaque rapport, une page rouge est insérée au début de chacun. Chaque rapport est numéroté dans le coin supérieur droit et contient, en plus, son titre propre et la description du contenu, ainsi que son lieu d'édition lorsqu'il ne s'agit pas d'un rapport divisionnel. Un résumé français est compris avec chaque rapport.

VOL. 2 Report 1

72-140 M. Savich

Effects of noise on man
and hearing protection

1972

Published in Sigurnost u Rudicima

(4) 1973

Effets du bruit sur l'homme et protection de l'ouïe

par

Miron Savich

RÉSUMÉ

Le bruit interfère avec le travail, le sommeil et les loisirs. Il entraîne aussi de la tension et de la fatigue, une perte d'appétit, des indigestions, de l'irritation et des maux de tête. Le bruit intense a des effets néfastes cumulatifs sur le mécanisme de l'audition humaine et peut provoquer une surdité temporaire ou permanente.

L'oreille humaine est un organe complexe qui reçoit les vibrations sonores environnementales. Le son est le résultat de deux processus :

1) un changement physique dans l'environnement relatif à la pression
2) un processus psycho-physique faisant intervenir la transmission.

Les deux principaux paramètres que nous utilisons pour définir et décrire des ondes sonores sont la fréquence (Hz) et l'intensité (dB). L'audiogramme est un graphique représentant le niveau d'audition d'une personne en fonction de la fréquence et de l'intensité.

Une perte d'audition due au bruit affecte généralement les deux oreilles chez les personnes âgées de moins de 40 ans. La presbyacousis est le terme

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Bruit : Perte d'audition : Législation et règlements : Protection de l'audition

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médical qui s'applique à la perte de sensibilité de l'oreille survenant naturellement avec l'âge. Le terme surdité est utilisé ici pour définir la perte d'audition consécutive à des accidents, à une maladie ou à une exposition à des bruits intenses; il exclut la presbyacousie. La perte d'audition causée par une exposition répétée aux niveaux de bruit que l'on rencontre souvent dans l'industrie et ailleurs est plus importante. Si l'exposition au bruit est composée de deux ou plusieurs périodes d'exposition à des bruits de différents niveaux, il convient de considérer l'effet combiné plutôt que l'effet de chaque période d'exposition. Les expositions à des bruits inférieurs à 90 dBA ne sont pas considérées dans les calculs (The American Conference of Governmental Industrial Hygienists for 1969). L'American Standards Association a établi des normes pour les niveaux de bruit indésirables et dangereux. Les critères de Rosenblith et Stevens sont considérés sûrs pour des expositions au bruit pendant la durée d'une vie.

Au cours des vingt dernières années, les dommages auditifs ont augmenté rapidement en raison de l'introduction d'engins plus lourds dans les mines. Ainsi, s'il est impossible de réduire les expositions au bruit excessives par d'autres moyens, il convient de porter des casques protecteurs. Le but de cette protection est de réduire la quantité d'énergie sonore transmise à l'oreille interne.

À l'heure actuelle, nous ne disposons pas de moyens de réduire totalement le bruit émis par un grand nombre d'engins utilisés dans les mines. Il faut donc consacrer un effort particulier à la mise au point et à l'adoption de systèmes de protection personnels efficaces et à la réduction du bruit émis par les engins.

Effects of Noise on Man and Hearing Protection

by

Miron Savich

ABSTRACT

Noise interferes with work, sleep and recreation. It also causes strain and fatigue, loss of appetite, indigestion, irritation and headache. High-intensity noise has adverse cumulative effects on the human hearing mechanism, to cause either temporary or permanent deafness.

The human ear is a complex organ which receives environmental sound vibrations. Sound is the result of two processes:

1) a physical change in the environment relating to pressure, and
2) a psycho-physical process which involves the transmission.

The two main qualities which we use to identify and describe sound waves are frequency (Hz) and intensity (dB). The audiogram is a graph that shows a person's hearing level as a function of frequency and intensity.

A noise-induced hearing loss generally affects both ears in persons under 40 years of age. Presbycousis is the medical term for the loss of

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Noise: Hearing Loss: Legislation and Regulations: Hearing Protection

* Elliot Lake Laboratory, Mines Branch, Mining Research Centre, Department of Energy, Mines and Resources, Elliot Lake, Ontario.

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sensitivity of the ear which occurs naturally with increasing age. The term deafness is used here for the hearing loss due to accidents, disease, or exposure to loud noises, and excludes presbycousis. More important is the hearing loss caused by exposure over periods of time to the noise levels that often occur in industry and elsewhere. If the noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. Noise exposures of less than 90 dBA do not enter into the above calculations (The American Conference of Governmental Industrial Hygienists for 1969). American Standards Association established standards for undesirable and injurious noise levels. Rosenblith and Stevens criteria levels were considered to be safe for lifetime exposures.

In the last twenty years, audiometric damage rapidly increased because of the introduction of larger machines in mining. For this reason, and if excessive noise exposures cannot be reduced by other means, ear protectors should be worn. The object of such protection is to reduce the amount of sound energy transmitted to the inner ear.

Presently we do not have solutions for total noise reduction from many mining machines. Because of this, a lot of effort must be given for the development and adoption of effective personal protection and for reduction of machine noise.

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1. INTRODUCTION

Noise, music and speech are three basic categories of sound. The human voice and the human ear constitute the fundamental natural sound system. Basic understanding of sound and the human ear is essential for acoustical studies and measurements.

Noise is defined as unpleasant or unwanted sound. Technically, noise is the combined result of single-frequency sounds or pure tones, and has a continuous frequency spectrum of irregular amplitude and waveform. Infrasound is noise of frequency less than 20 Hz, while ultrasound is noise of frequency greater than 20, 000 Hz (1).

Noise interferes with work, sleep and recreation. It also causes strain and fatigue, loss of appetite, indigestion, irritation and headache. High-intensity noise has adverse cumulative effects on the human hearing mechanism, and causes temporary or permanent deafness. Psychologically, noise affects the output of workers, decreases their efficiency, and increases their liability to error and injury because of distraction from work. Processes leading to emission of noise from machines can also cause wear and damage (2, 3, 4, 5, 6).

In mining, we have noisy devices and noisy environments. Subjective discomfort often diminishes as the miner continues to work and comes to accept the noise as a natural background to his task, particularly when he himself contributes to noise through his job.

2. PSYCHOACOUSTICS AND ANATOMY OF THE EAR

The human ear is a complex organ which receives environmental sound vibrations, transmits signals accurately to the brain for interpretation, and also governs our sense of balance.

2.1 Nature of Sound

Sound is the result of two processes:

i) a physical change in the environment relating to pressure, and

ii) a psycho-physical process which involves the transmission, perception, and interpretation of the sound in one's consciousness.

The first stage of sound production is the creation of sound waves (vibrations of air molecules) which are set into motion in all directions from a central vibrating source, e. g., a vibrating string on a musical instrument that has just been plucked. The moving air particles cause pressure variations in the surrounding air, which eventually reach the ear and bring about similar pressure changes or impulses at the highly sensitive eardrum; this then starts the psycho-physical process of "hearing". The two main qualities which we use to identify and describe sound waves are frequency (pitch) and intensity (loudness).

The audiogram is a graph that shows a person's hearing level as a function of frequency (Hz) and intensity (dB). Audiometry is a technique of determining how well we hear pitch sounds at different intensities, especially those pitches which are critical to understanding speech (Figure 1).

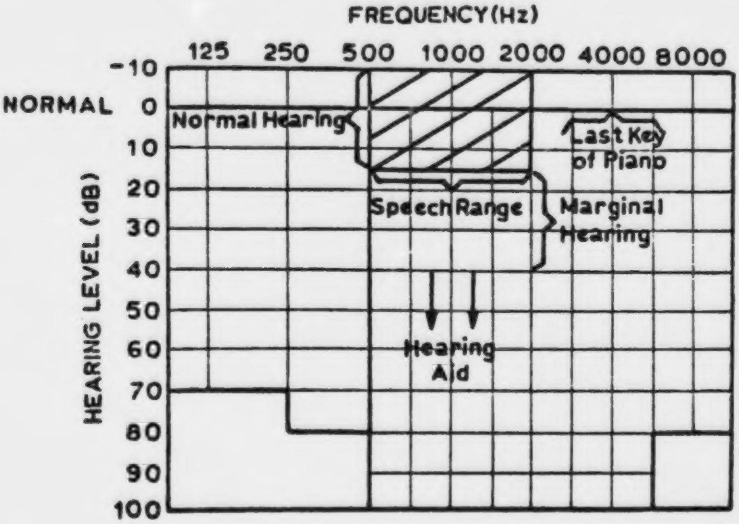


Figure 1: The Hearing Level as a Function of Frequency (Hz) and Intensity (dB).

2. 2 Anatomy of the Ear

Basically, the ear is divided into three parts: the external or outer ear, the middle ear, and the inner ear.

a) Outer Ear

The outer ear is composed of the external ear (pinna) and the ear canal (external auditory meatus). What we commonly refer to as an "ear" is, in fact, only the outer ear. The function of the outer ear is to collect sound waves approaching the ear and to concentrate them on to the ear drum (Figure 2).

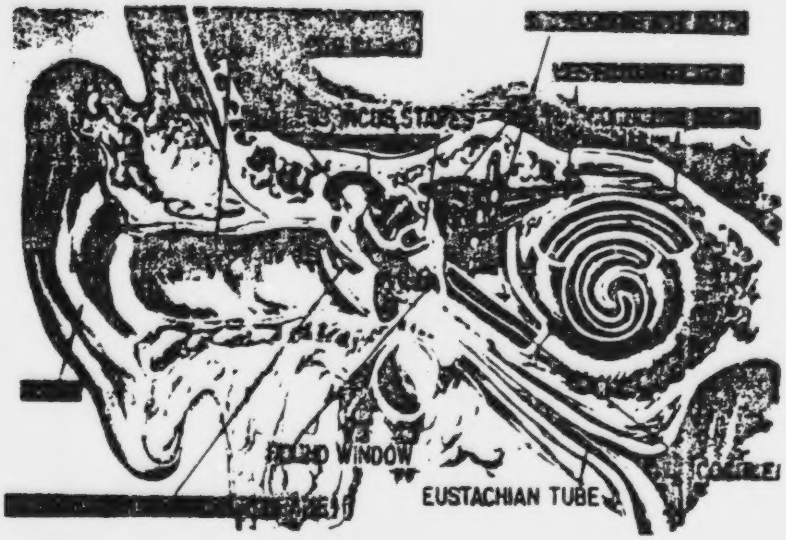


Figure 2: Anatomy of the Ear.

b) Middle Ear

The middle ear begins at the ear drum (tympanic membrane) and contains the three smallest bones of the body, called the hammer (malleus), anvil (incus) and stirrup (stapes). These tiny bones are connected in a chain-like fashion, being attached at one end to the inside of the eardrum and at the other to the membrane covering the inner ear and its viscous fluid. Upon movement of the eardrum, this bony chain moves inward, transmitting the pressure wave to the heavy inner ear. Also in the middle ear are two muscles, the tensor tympani and the stapedius, which help to prevent the transmission of potentially overpowering vibrations to the inner ear. The middle ear also contains the Eustachian tube which extends from the floor of the middle ear cavity into the throat and helps to ventilate the middle ear and equalize pressure (Figure 2).

c) Inner Ear

The inner ear contains the semi-circular canals, the sense organs of balance and the cochlea, or sense organ of hearing. Vibration of the footplate of the stirrup (stapes) which contains the oval window, causes the fluid (perilymph) in the cochlea to move (Figure 2).

d) Analysis of Sound by the Cochlea

The snail-shaped organ (cochlea) is divided into an upper portion (scala vestibuli) and a lower portion (scale tympani), both containing fluid (perilymph). The triangular compartment (scala media) is formed on the lower side by a bony ridge (osseous spiral lamina) and the basilar membrane attached to the spiral ligament, and on the upper side by the vestibular membrane (Reisener's) which is also attached to the spiral ligament. The cochlear duct is filled with fluid (endolymph). The organ of Corti is located on the basilar membrane and contains the hair cells (sensory end-organs) which are attached to the gelatinous tectorial membrane. The hair cells are arranged in rows: one row of inner hair cells and three or more rows of outer hair cells. High-frequency tones are transmitted at the basal end of the cochlea, while low-frequency tones are transmitted near the apex. Middle frequencies activate the second turn area of the basilar membrane. The fluid movement causes the membranes to move, thereby stimulating the hair cells which trigger electrical impulses that activate the fibers of the eighth cranial (auditory) nerve. The nerve transmits these impulses to the brain which

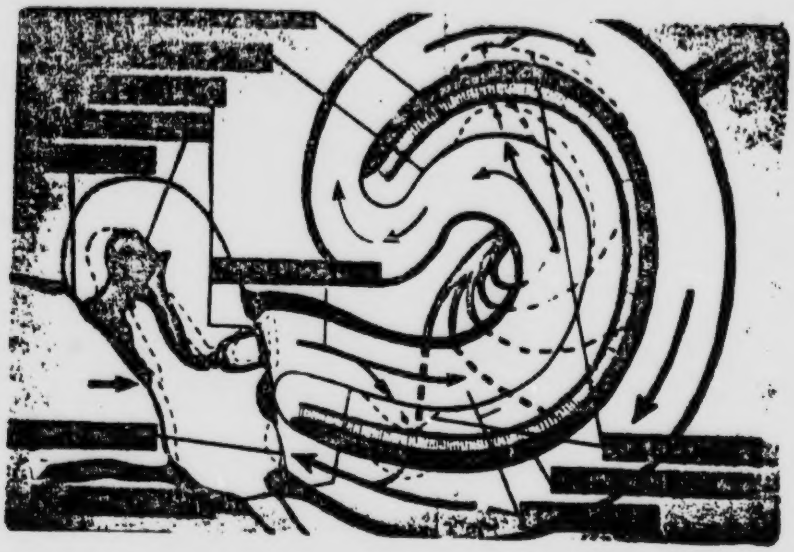


Figure 3. 1: The Inner Ear and the Cochlea.

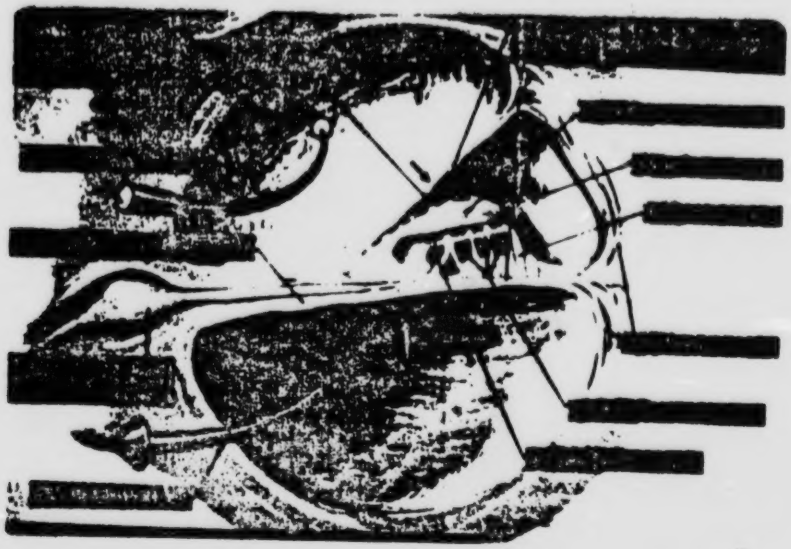


Figure 3. 2: The Cochlea - Section

interprets the sounds it receives from the ear (Figures 3. 1 and 3. 2).

In summary, the ear functions by transforming a vibrating source from acoustic energy into mechanical energy in the middle ear; into hydraulic energy in the inner ear; into electrical impulses along the eighth nerve; and finally into psychological or semantic impulses at the auditory cortex (Figure 4).

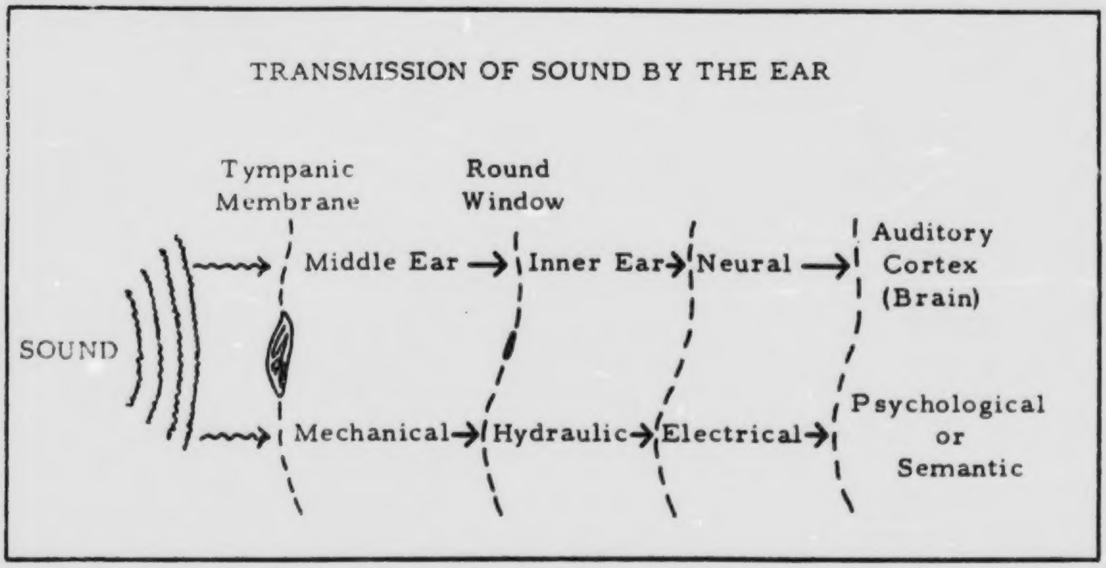

TRANSMISSION OF SOUND BY THE EAR
Tympanic Membrane
Round Window
SOUND
Middle Ear
Inner Ear
Neural
Auditory Cortex (Brain)
Mechanical
Hydraulic
Electrical
Psychological or Semantic

Figure 4: Transmission of Sound by the Ear.

2. 3 Pathology of a Noise-Induced Hearing Loss

A noise-induced hearing loss initially damages the sensitive hair cells in the organ of the Corti, causing a loss of acuity at 4000 Hz. If a person's ability to hear conversational speech has not been affected, the hearing loss usually goes undetected in its temporary or transient stage.

However, when the loss also involves the lower frequencies, it is more severe in degree and affects the person's ability to understand speech. It has become a permanent hearing loss. Obviously, these two types of hearing loss have many gradations between them, with the former tending to be replaced by the latter if not recognized and treated. A noise-induced hearing loss generally affects both ears in persons under 40 years of age. Some individuals seem more sensitive to loud sounds, and therefore are more susceptible to this type of hearing impairment than others (7).

2.4 Presbycousis

Presbycousis is the medical term for the loss of sensitivity of the ear which occurs naturally with increasing age. One common provision deducts 1/2 dB from the person's average hearing level for every year beyond age 40. At the higher frequencies, there are undoubtedly considerable losses. It is important when assessing hearing loss due to exposure to loud noises to allow for presbycousis (7).

2.5 Deafness

The term deafness is used here for the hearing loss due to accidents, disease, or exposure to loud noises, and excludes presbycousis. There are three main types of deafness: conductive, nerve, and cortical.

Conductive deafness is due to defects in those parts of the ear which "conduct" the sound waves in the air to the inner ear. This type of deafness either affects all frequencies more or less equally or, more typically, is more severe at the low and middle frequencies.

Nerve deafness (sometimes called perceptive hearing loss) is due to loss of sensitivity in the sensory cells in the inner ear or some defect in the auditory nerve. This type of hearing loss has no medical remedy. The hearing losses caused to people working for long periods under very noisy conditions are of this type.

Cortical deafness chiefly affects old people and is due to a defect in the brain centres (7).

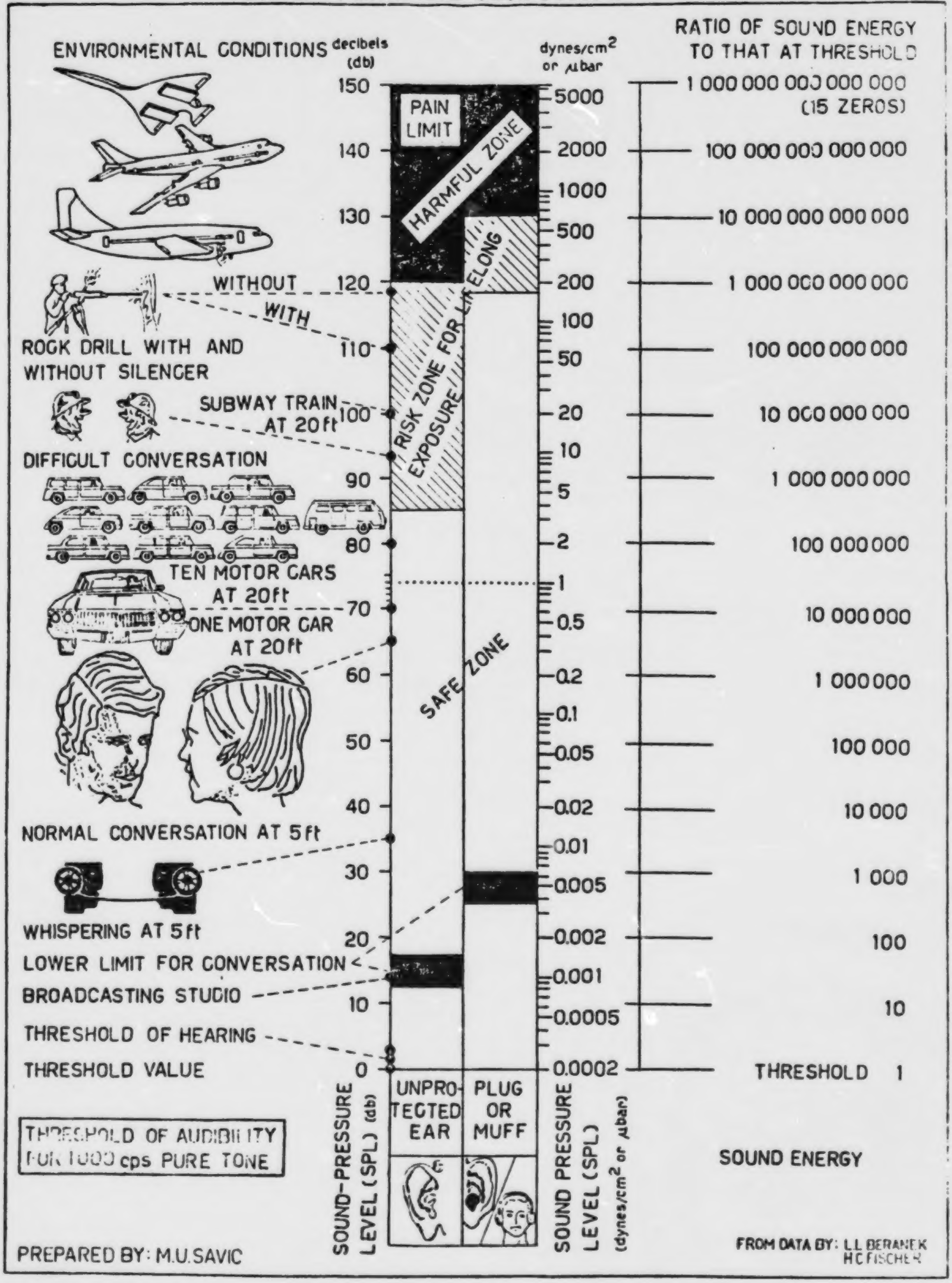
2.6 Deafness Caused by Noise

If a noise is loud enough, it will immediately damage the ear drum, perhaps so badly that it will not heal, or destroy the delicate ossicles. It is not known with any accuracy how loud a noise must be to cause such serious damage because experiments of this nature are not made on human beings, but from experiments on animals and from such accidents to humans that have been investigated, it appears to be of the order of 150 dB (Pain Limit) (See Table 1).

Of more general importance is the hearing loss caused by exposure over periods of time to the noise levels that often occur in industry and elsewhere (amplified music, etc.). Exposure to these noises causes nerve deafness, i. e., damage to the sensory cells of the inner ear, or possibly to the auditory nerve. No surgical remedy is possible. Like presbycousis, nerve deafness due to loud noise tends to affect first the higher frequencies (above 1000 Hz) but, unlike presbycousis, this loss will often, if severe enough, extend over the whole frequency range.

TABLE 1

ENVIRONMENTAL CONDITIONS



Temporary hearing loss may be caused by noise, but, if the noise is not too loud and not prolonged, the person will, in time, completely recover his hearing. The period of recovery may be anything from a few seconds to months, depending on the nature of the noise exposure and on the person himself. However, we are concerned here only with permanent hearing loss.

The establishment of maximum permissible sound pressure levels is extremely difficult. In spite of the vast amount of work done, not enough has been learned to deal with all the variables. These variables are as follows:

- the loudness and nature of the noise;
- whether the exposure is intermittent;
- the previous exposure of the person to noise; and
- the different physical reactions of different people to the same noise.

2.7 Effects of Noise on Man

Now the manner in which acoustic energy impairs the ear can be described. This description also offers criteria indicative of noise environment likely to cause permanent hearing loss.

In mining, there are very often cases of temporary hearing loss. Sudden intense noise (blast, explosion) may produce severe damage to the structures of the middle and inner ear. The eardrum may be ruptured and the continuity of the ossicular chain may be destroyed. Damage of this kind is undoubtedly caused by the sudden increase and decrease of pressure caused by the passage of the wave front of the blast. The sensori-neural effects of sudden trauma usually do not stabilize until several months have elapsed.

Hearing loss caused by sudden trauma is usually referred to as "acoustic trauma", which may occur following a single sudden sound such as a pistol shot or a blow to the head. The mechanism of acoustic trauma is very involved and little is known about the character of the trauma (Figure 5).

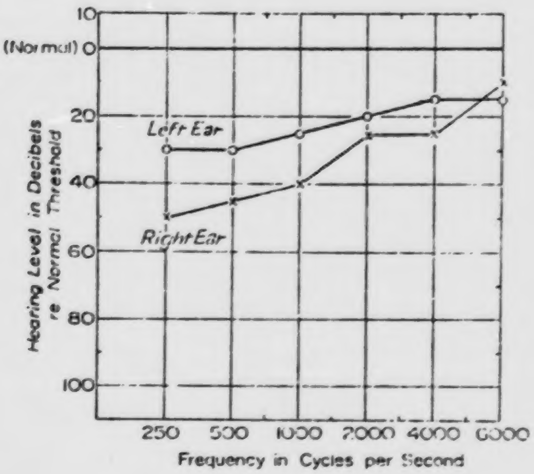


Figure 5: Conductive Hearing Loss Caused by an Explosion.
Source: Industrial Noise Manual, Second Edition.

Some people lose their hearing for only a portion of the pitch range. When this happens, they continue to hear certain sounds normally but fail to hear other sounds. Parts of words and parts of sentences are missed, and the person's greatest problem is an inability to hear clearly. Many people have a hearing loss for the higher-pitched sounds and experience problems in understanding what is being said because they do not hear many key sounds in our language, such as (s), (sh), (ch), (t), (p), (th), (f), etc. (7). It is quite easy to miss a key sound in a word, which, in turn, could change a key word in a sentence. As a result, an entire sentence could be misunderstood. This condition is commonly referred to as a speech discrimination loss. It can be accompanied by a general loss in sensitivity, an inability to hear most sounds loudly enough, or a partial loss in sensitivity, an inability to hear some sounds loudly enough.

The normal development of speech is closely related to hearing ability. Speech does not develop normally if a child has a significant hearing loss in early life. If a hearing loss develops after normal speech has been acquired, there is a chance that the person's speech will become noticeably impaired (Figure 6).

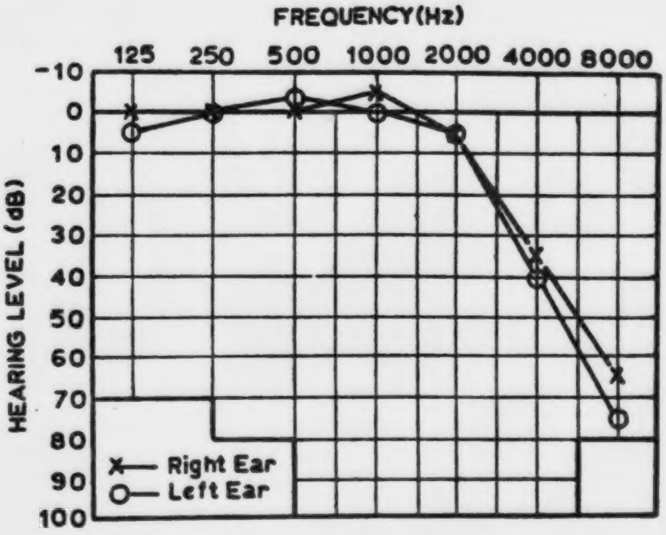


Figure 6: A Hearing Loss above 2000 Hz.

Speech problems resulting from a hearing loss can be of two distinct types. The first of these is loud speech (shouting) as a result of a general loss of sensitivity for all speech sounds.

The second type of speech problem commonly associated with hearing loss is usually referred to as an articulation problem. It results from errors in producing certain sounds correctly and is associated with an inability to hear them. For example, if a person does not hear the high frequency sounds such as (s), (sh), (t), (p), (th), he cannot be expected to include them in his speech (7).

Persons with this kind of hearing loss can get along fairly well in a quiet listening situation but, as soon as they are in a place where background noise is present such as in traffic in underground mining, it becomes difficult to communicate through hearing alone (Figure 7). This type of background noise contains many low-pitched sounds which interfere with good hearing of low-pitched speech sounds. Thus, the hearing interference caused by noise plus the hearing loss resulting from damage to the ear cause a greater hearing problem than would exist for one of these conditions alone.

The last example of hearing impairment involves a combination of a mild to moderate loss in sensitivity for sounds across a rather broad pitch range from 125 Hz to 8000 Hz. A hearing loss of this type is shown in Figure 9. Sounds are difficult to understand not only because they are not loud enough but because they are also distorted for the person

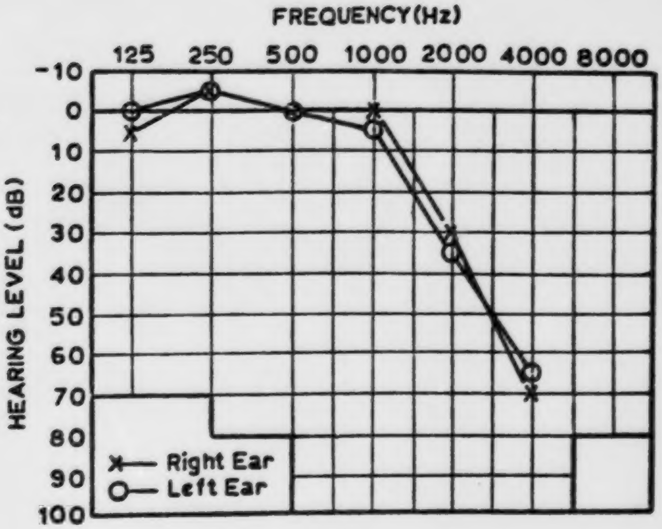


Figure 7: A Hearing Loss above 1000 Hz.

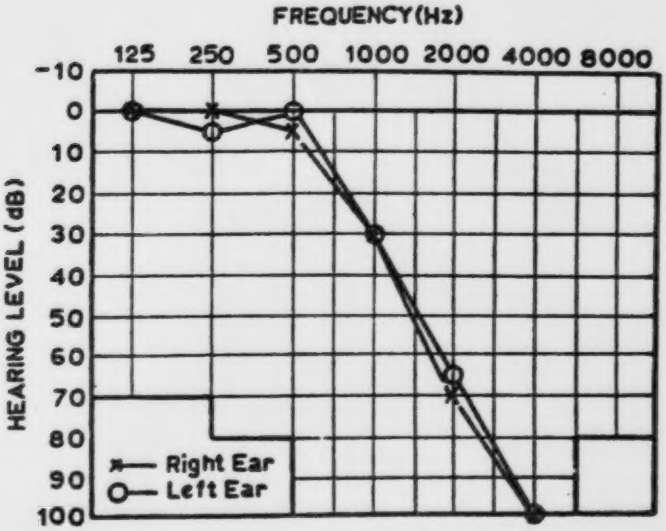


Figure 8: The Speech Sounds above 500 Hz Are Missing.

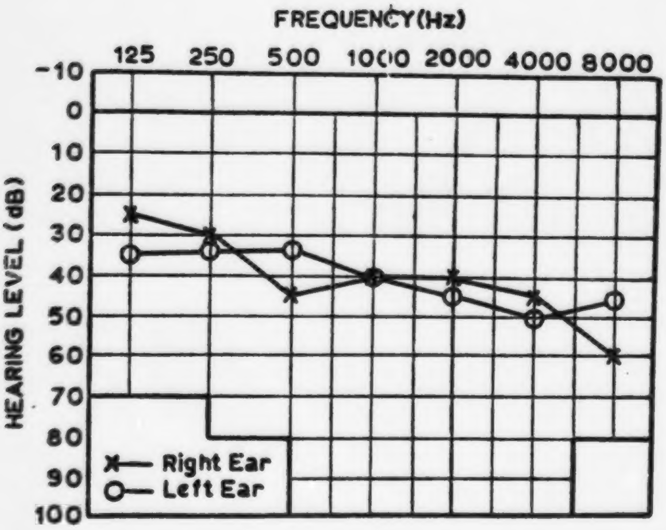


Figure 9: Audiometric Record Illustrating a 40-dB Hearing Loss.

who has this type of impairment (increasing loss for higher frequencies). Even when the passage is louder, the person will have trouble understanding what is being said because it is not clear. This is a problem sometimes encountered in persons who have had damage to the delicate inner ear mechanism where sounds are received by the ear and converted to electrical signals which are sent to the brain for interpretation.

2.8 Threshold Limit Values (The American Conference of Governmental Industrial Hygienists - ACGIH for 1969).

These Threshold Limit Values refer to sound pressure levels that represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effect on their ability to hear and understand normal speech. The sound level shall be determined by a sound level meter, meeting the standards of the United States of America Standards Institute and operating on the A-weighting network with slow meter response.

TABLE 2

Permissible Noise Exposures*

Duration Per Day Hours	Sound Level dBA[a)]
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
3/4	107
1/2	110
1/4	115-C [b)]

a) Sound Level in Decibels as Measured on a Standard Level Meter Operating on the A-weighting Network with Slow Meter Response.

b) Ceiling Value.

* Threshold Limit Values of Physical Agents Adopted by ACGIH for 1969.

If the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered rather than the individual effect of each. If the sum of the following fractions exceeds unity, i. e.,

$$\frac{C1}{T1} + \frac{C2}{T2} + \ldots \frac{Cn}{Tn} > 1$$

where C1 indicates the total time of exposure at a specified noise level;

T1 indicates the total time of exposure permitted at that level;

then the mixed exposure should be considered to exceed the threshold limit value. Noise exposures of less than 90 dBA do not enter into the above calculations. Impulsive or Impact Noise should not exceed 140-dB peak sound pressure level-C.

American Standards Association, Standard (Z24-X-2), investigated the feasibility of establishing standards for undesirable and injurious noise levels and attempts to relate hearing loss to a single overall level obtained with sound level meters have been made by several individuals.

In 1953 Rosenblith and Stevens published their criteria for continuous spectrum noise and for narrow band noise (Figure 10). It was intended that adherence to these criteria would result in no statistical differences in hearing thresholds for pure tones between noise-exposed populations and those not exposed to noise. The criteria levels were considered to be safe for lifetime exposures.

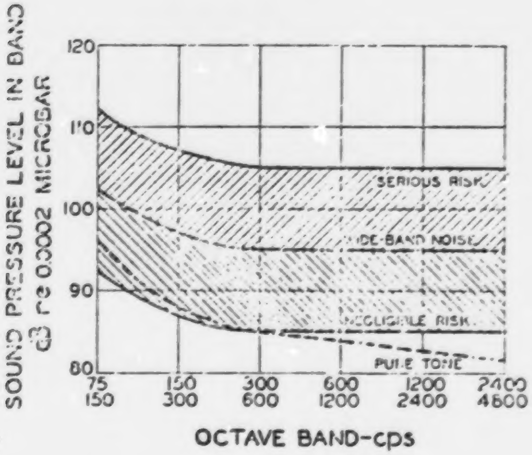


Figure 10: Damage Risk Graph, after Rosenblith and Stevens.

3. HEARING PROTECTION

In the last few years audiometric damage rapidly increased because of the introduction of larger machines in mining. For this reason and if excessive noise exposures cannot be reduced by other means, ear protectors should be worn. The object of such protection is to reduce the amount of sound energy transmitted to the inner ear (Figure 11) (3, 6, 8).

3. 1 Reduction to Transmission by Air Conduction

3. 1. 1 Cotton. Cotton ear plugs are not advised on account of their inefficiency and the false sense of security which their use engenders; however, if the cotton is mixed with petroleum jelly or paraffin wax it becomes much more efficient.

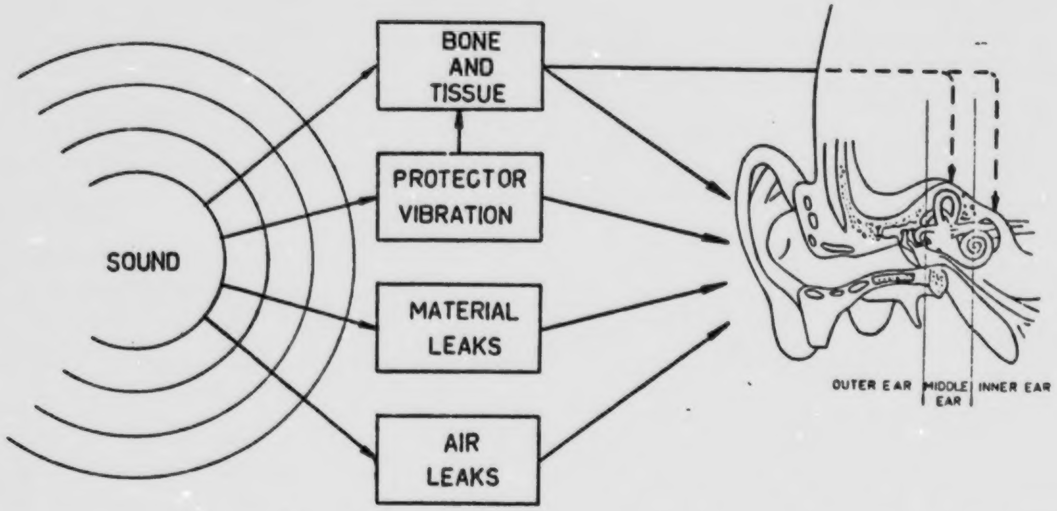

SOUND
BONE AND TISSUE
PROTECTOR VIBRATION
MATERIAL LEAKS
AIR LEAKS
OUTER EAR
MIDDLE EAR
INNER EAR

Figure 11: Noise Directions to the Inner Ear.

3.1.2 Anti-Noise Ear Stopples. Anti-Noise Ear Stopples are made of cotton impregnated with a special formulation of wax (Figure 12.2). They are pliable and easily molded by hand to fit any ear size (Figure 13). When inserted, they completely seal the opening of the ear, providing greater protection from noise than most rigid rubber or plastic devices and the user can easily hear spoken instructions. Low in cost, Anti-Noise Ear Stopples are disposable after each use. They are available in bulk or individual packages.

3.1.3 "Glass-Down" (Swedish Wool). (Figure 12.1) Probably the most practical and acceptable of the disposable forms of ear plugs are those made of "glass-down". This is a form of glass wool which, as far as it has been possible to ascertain from its extensive use both in Canada and in other

1
2
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Figure 12. 1 "Glass-Down" (Swedish wool)
2 Anti-Noise Ear Stopples

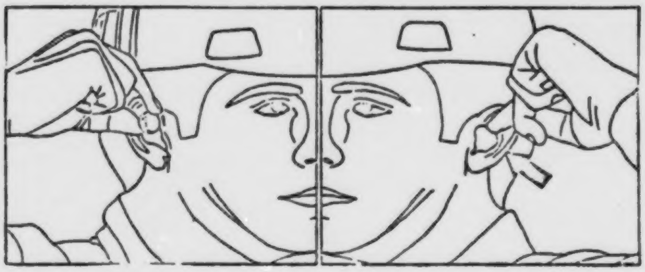

Figure 13: Anti-Noise Ear Stopples.
These are comfortable, easy to use, economical, disposable. . . no fitting needed.

TABLE 3

Tests Conducted in Accordance with USA Standard Z24. 22-1957

Frequency cps	Mean Sound Attenuation (in dB)		
	Plain Cotton*	Quiet Down	Ear Stopples
125	5	9	19
250	6	16	20
500	8	19	21
1000	9	23	26
2000	13	28	30
3000	15	38	38
4000	13	40	40
6000	14	34	41
8000	16	30	36

* Industrial Noise - A Guide to Its Evaluation and Control, U.S. Public Health Service.

countries, is quite harmless even to the delicate skin of the ear canal. To be used effectively, and to avoid pieces of "glass-down" being left in the meatus, the plug must be folded according to the instructions provided with it. The method of folding a plug is illustrated in Figure 14. For industrial use on a large scale, a satisfactory form of dispenser is available. The attenuation characteristics are shown in Table 3.

3.1.4 Ear Plugs. Prefabricated ear plugs are made of rubber or plastic, and usually are supplied in a variety of sizes. One of the most efficient ear plugs, and certainly the most widely used of the types that are intended for personal issue and repeated use is the plug generally known as the "V-51R" (Figure 15). It consists of a soft plastic bung carrying a flexible flange in order to conform to the shape of the external meatus and make as complete a seal as possible. The plug was originally produced in five sizes, but several manufacturers have reduced them to three. The bullet-shaped, air-filled device (Figure 15.1) comes in seven sizes and is excellent for round and straight canals.

The multi-flanged plug, available now in only one size, requires no ear measurement (large and small are available for unusually large and unusually small ear canals). The plug is designed to perfectly seal the ear. It is non-toxic and non-allergenic; is resistant to ear-wax and skin oils; and can be boiled and sterilized. High attenuation is significantly better when the two flanges can enter and closely contact the ear canal and the third can

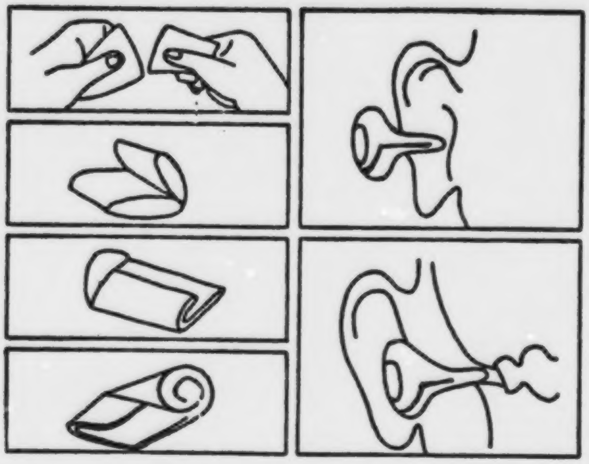

Figure 14: Method of Forming a "Glass-Down" Ear Plug

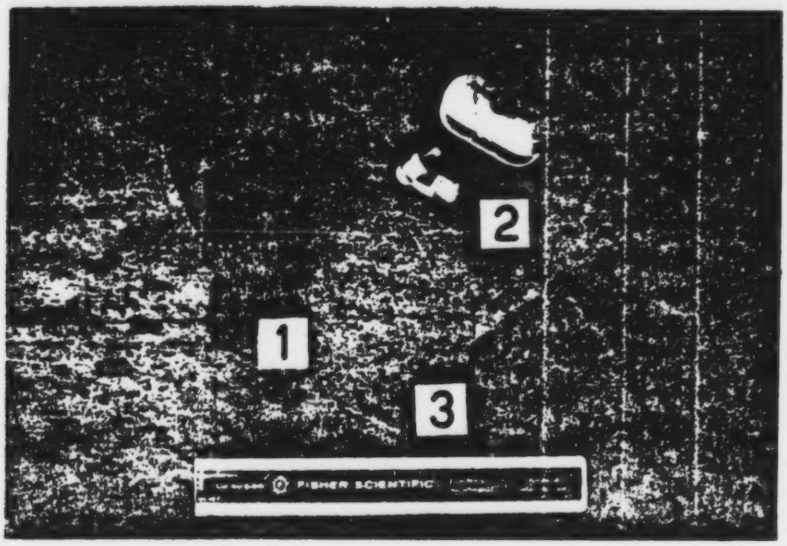
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Figure 15:
1. The Bullet-Shaped Ear Plug.
2. "V-51R" Ear Plugs.
3. The Multi-Flanged Plug.

block off the opening (Figures 15.3 and 16).

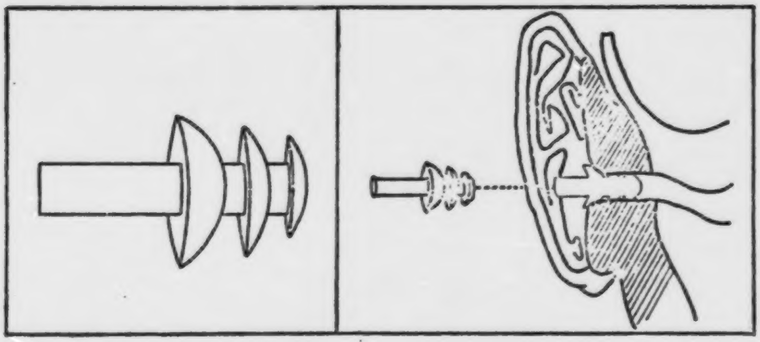

Figure 16: The Multi-Flanged Plug.

Lee Sonic Ear-Valv* is a precision engineered device that safeguards hearing by regulating and controlling the passage of sound into the ear canal. It is a revolutionary, proven hearing protector, which operates against over-pressures of loud sound. In quieter areas, the desired sound passes through undisturbed and is not blocked as with earplugs or earmuffs. Hearing of speech and desired sound is improved in the loud-noise areas. It permits normal relaxed hearing under all conditions, yet affords ultimate hearing protection in the presence of loud harmful noises (Figure 17). Lee Sonic Ear-Valvs do not create a stuffed head feeling as with ear plugs. The air canal is left open to normal air circulation, thus eliminating the hazards of dizziness and temperature change. They let workers hear instructions, machine irregularities, etc. (without removing)

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* U.S. Patents 2465606, 2619960.

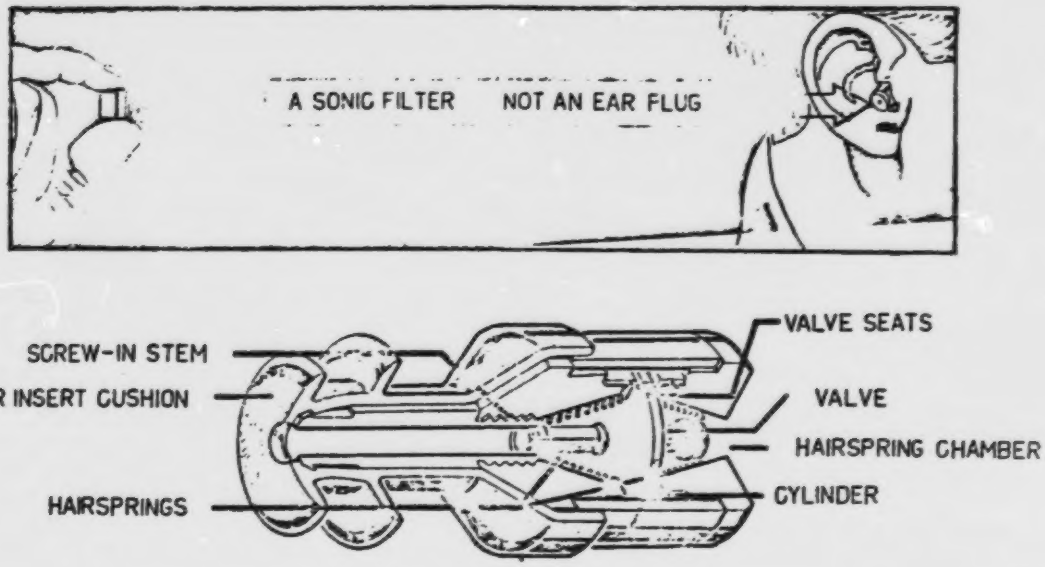
A SONIC FILTER
NOT AN EAR PLUG
SCREW-IN STEM
EAR INSERT CUSHION
HAIRSPRINGS
VALVE SEATS
VALVE
HAIRSPRING CHAMBER
CYLINDER

Figure 17: Mechanical Hearing Protector: Lee Sonic Ear-Valv.

-- reducing the possibility of accidents.

The Lee Sonic Ear-Valv insert cushion comes in one universal size. Made of special formula silicone rubber, it assures maximum comfort, may be sterilized, is non-allergenic, non-toxic, resistant to ear-wax and natural body oils. It is replaceable at reasonable cost and will last indefinitely under normal use.

Lee Sonic Ear-Valvs are recognized and approved by leading ear specialists, insurance companies and safety engineers. However, one author states, "Those who have tested it do not find that it performs as claimed. It provides little protection in steady noise such as that produced by rock drills" (9).

3.1.5 Ear Muffs These are rigid cups specially designed to cover the external ears completely. Two such cups are held in place by an adjustable headband or are mounted on a helmet. Each cup has a soft cushion filled with plastic foam or a fluid such as glycerine, to ensure a good fit between the cup and the head; the fluid-filled cushion is called a "fluid-seal" (Figure 18) (10).

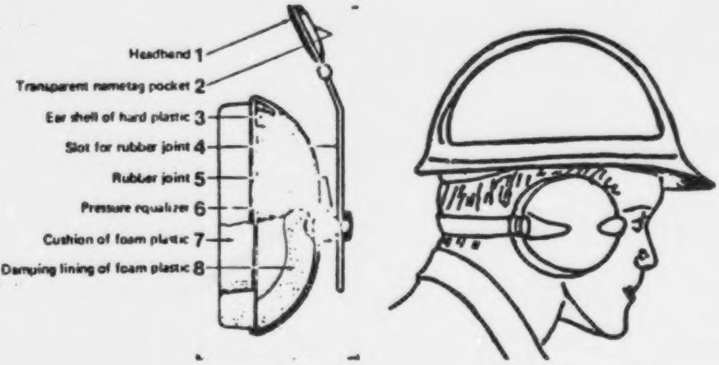
Headband 1
Transparent nametag pocket 2
Ear shell of hard plastic 3
Slot for rubber joint 4
Rubber joint 5
Pressure equalizer 6
Cushion of foam plastic 7
Damping lining of foam plastic 8

Figure 18: Back-Band Hearing Protector.

The muff-type hearing protector for use in high-noise areas provides its maximum attenuation in the most dangerous frequencies and still permits the wearer to hear and conduct conversation. It will fit virtually any head size and is available as free-fitting or attached to safety hats. Special adaptors are not required; there is no need to drill holes for special mounting screws. Headgear and hearing protector are independent units, either can be worn separately. It has the same inherent advantages of comfort, universal fit, and air-controlled seals.

Contour-shaped ear cups match bone structure around the ear for a better fit and for comfort, yet allow the wearer to hear and converse comfortably in most noise areas. Air-controlled seals, filled with foam material, always return to the original shape after wearing. Transmission of noise and vibration from cap to ear cup is minimized by a special design feature that combines spring coil, an insert, and a neoprene washer that dampens vibrations.

If we compare the attenuation of different ear protectors, the best effect is achieved by the use of ear plugs and muffs. The attenuation values shown in Table 4 are for different ear protectors and were obtained from the measured spectrum of the exposure noise. The best attenuation is obtained with a good imperforate insert ear plug (V-51R) and a good muff protector (Model 372-9A).

TABLE 4

Real-Ear Attenuation of Ear Protectors at Threshold dB Re 0.0002 Microbars

Octave Bands in cps	Dry Cotton	V-51R Ear Plugs	372-8A Muffs	V-51R and 372-8A in Combination
75- 150	4	24	19	37
150- 300	6	24	23	35
300- 600	7	26	37	40
600-1200	9	29	38	40
1200-2400	12	37	31	39
2400-4800	14	36	42	50
4800-9600	15	40	40	45

Source: Industrial Noise Manual
(Copyright 1966 by American Industrial Hygiene Association)

3.2 Reduction of Transmission by Bone and Tissue Conduction

Bone and tissue conduction are important in several contexts. It accounts for the "shadow" audiogram found in patients with severe unilateral deafness, and in clinical diagnosis it means that any unilateral hearing loss much greater than 60 dB cannot be wholly conductive. The maximum amount by which an ear protector can reduce the sound reaching the ear is limited to about 35 dB at a frequency of 250 Hz up to about 60 dB at the higher frequencies; the addition of helmets which seal off the whole head, can, however, increase the sound attenuation by another 10 dB, after which conduction of sound by the body as a whole adds a further limitation.

3.2.1 Helmets. Helmets are commonly used to support ear muffs or ear phones and cover the bony portion of the head in an attempt to reduce bone conducted sound (Figure 11). They are suited for use in high noise levels, both for communication purposes and if additional safety, such as protection of the eyes and of the head, is required. With good design and careful fitting of the area between the edges of the helmet and the skin of the face and neck, a further 5 to 10 dB of sound attenuation can be obtained in addition to that already provided by the ear muffs or ear phones within the helmet. The kit (helmet supporting ear muffs) is designed specially for mounting on industrial safety caps.

3.2.2 Cold Weather Helmet with Ear Protectors. These units (Figure 19) combine the maximum noise attenuation (to protect the human ear from loud ear-damaging noise) with the warmth of a winter liner. The

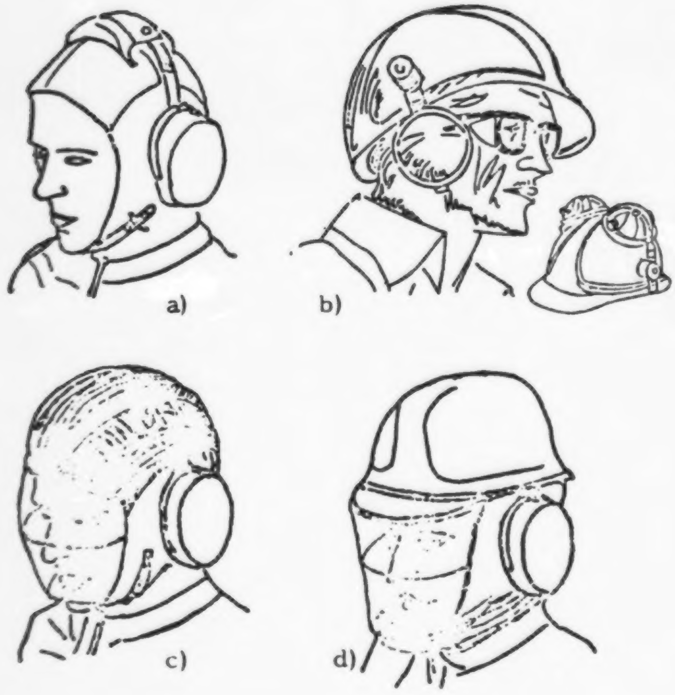

Figure 19: Ear Protection

a) Cold weather helmet with ear protectors.
b) Cap-mounted hearing protector.
c) New cold weather helmet with ear protectors (suggestion).
d) New cold weather cap-mounted hearing protectors (suggestion).

"muff-type" ear protectors are integrated with a cold-weather, top-quality cotton twill helmet, lined with nylon fleece.

The ear protectors themselves, going over the ear and not in it, keep noise out by intercepting and breaking up the sound waves as they hit the domes. The domes are tightly sealed to the head around and over the ears, protecting the canals and ear drums. The cycolac domes also have high impact strength and are light in weight. Their foam-filled seals, used to couple the domes to the head, are of vinyl and filled with polyurethane. Ear seals and head pads can be easily removed for servicing.

The helmet shown in Figure 19 (b) is not adequate at low temperatures. The cold weather helmet with ear protectors (Figure 19 a) does not provide protection for the eyes and the head against injury. In both cases, the nose and mouth are not protected and this is very important in low temperatures. The proposed solution is shown in Figure 19 (c) and (d).

The design of the universally effective cold weather helmet with ear and eye protectors is a complicated project. There are considerable differences in the horizontal distance between eyes and ears; the location of ears with reference to the top of the head; the angle of attachment of outer ear to head.

4. CONCLUSION

Presently it is not practical to further reduce the noise from many mining machines. Therefore, great emphasis should be placed on the development and adoption of effective personal protection pending new designs for reduction of machine noise to acceptable levels.

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Vol. 2 Report 2

78-11 (CF) M. Savich

Ear muff noise attenuation

in Canadian mines

1978

ATTÉNUATION DU BRUIT À L'AIDE DE CASQUES ANTIBRUIT DANS LES MINES CANADIENNES

par

M. Savich*

RÉSUMÉ

Résumé :

Les performances de onze casques antibruit disponibles dans le commerce ont été évaluées au laboratoire; neuf de ces casques ont été essayés dans des mines. Les essais sur le terrain ont permis de rejeter ou de confirmer les résultats initiaux des essais de laboratoire. Les trois meilleurs casques antibruit ont été sélectionnés. Sont incluses des suggestions pour des travaux futurs.

De nos jours, les casques antibruit font partie du matériel de sécurité utilisé dans les mines canadiennes et, partant, nous avons mené une étude sur l'efficacité de ces casques.

Les résultats détaillés de l'étude théorique et expérimentale menée au laboratoire avec onze casques antibruit disponibles dans le commerce montrent que les relations entre la force de serrage (force du serre-tête) et l'atténuation ne sont pas encore éclaircies. Les principales caractéristiques des casques antibruit ont été étudiées par :

Mots-clés : Casque antibruit, force de serrage, confort, atténuation, laboratoire, mines.

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1) une méthode psycho-physique

2) une méthode physique

Nous avons obsrevé les effets suivants :

- la taille de la tête influe considérablement sur l'atténuation en raison de la différence dans la force de serrage;
- la quantité de cheveux emprisonnés entre les coussinets et la tête a un effet important sur l'atténuation par le casque antibruit;
- il n'y a pas de relation entre l'atténuation et le confort;
- l'atténuation diminue lorsqu'on utilise des lunettes avec leur adapteurs. Les adapteurs ne constituent pas des barrières efficaces;
- on n'observe pas de grande différence dans l'atténuation lorsque le cou bouge;
- les casques antibruit de diverses marques n'ont pas la même efficacité;
- les casques antibruit dont la surface des coussinets est petite deviennent efficaces plus rapidement car la force par unité de surface est plus grande;
- une force de serrage supérieure à 900 (g pds), dans les principaux casques antibruit, ne se traduit pas par une plus grande atténuation;
- il existe une certaine coïncidence entre les caractéristiques d'atténuation (ANSI Z24.22 - 1957) des casques antibruit et les essais physiques.

Neuf casques antibruit parmi les onze ont été essayés dans des conditions uniformes dans des mines. Les trois meilleurs ont été sélectionnés. Ces trois casques se portent derrière la tête. Le casque antibruit doté d'une bande de soutien, qui améliore le confort et assure un bon ajustage, offrait la meilleure atténuation. Les raisons d'une mauvaise atténuation sont nombreuses : mauvaise installation des oreillettes sur le casque, mauvais ajustage, interférence due aux cheveux et aux lunettes, port incorrect par les mineurs, mauvaise supervision, formation des mineurs incomplète, etc.

Les résultats de l'étude montrent qu'aucun des casques antibruit essayés ne possède toutes les caractéristiques que l'on devrait retrouver dans un casque idéal.

Étant donné l'atténuation insatisfaisante offerte par le casque antibruit dans des conditions de travail (~ 15 dBA), il devrait être exigé que les travailleurs portent un casque antibruit et des bouchons protecteurs seulement lorsque le niveau de bruit excède 105 dBA (certains auteurs recommandent 110 dBA).

Voici les clés de la solution au problème :

- le contremaître doit être en mesure d'aider les mineurs à porter correctement le casque protecteur et de faire appliquer le règlement;
- le programme doit être présenté aux mineurs;
- le contact avec les fabricants doit être constant.

Les expériences sur lesquelles sont basées les estimations de la force de serrage, du confort et de l'atténuation sont décrites en détail.

ATTENUATION OF EAR MUFFS IN CANADIAN MINES

by

M. Savich*

ABSTRACT

Summary:

Performances of eleven commercially available ear muffs were tested in the laboratory, and nine of them were tested in mines. Initial laboratory tests of the attenuation ability have been rejected or confirmed by field tests. Three ear muffs were chosen as the best. Suggestions for further work are included.

Today, in Canadian mines, ear muffs are a part of safety equipment, and because of this, research study was conducted to investigate the efficiency of ear muffs.

Detailed analysis of the theoretical and experimental solutions of eleven commercially available ear muffs in the laboratory showed that the relationships between clamping force (head band force) and attenuation remained unsolved. The main characteristics of ear muffs were investigated and analyzed by:

1) Psychophysical method, and
2) Physical method.

These investigations showed the following effects:

- head size has significant influence on the attenuation because of a different clamping force;
- test showed that the amount of hair trapped between the ear muff cushion and the head had a significant effect on ear muff attenuation;

Key words: Ear Muff, Clamping Force, Comfort, Attenuation, Laboratory, Mines.

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- attenuation and comfort are not in a casual relationship;
- with the use of glasses and their adapters, attenuation decreases. The adapters, are not effective barriers;
- there are no great differences in attenuation when the neck moves;
- the efficiencies of various brands of ear muffs are not equal;
- ear muffs with a small cushion area start serving their purpose more quickly because the force per area is larger;
- a clamping force larger than 900 (g wt), in the main ear muffs, does not cause an increase in attenuation; and
- attenuation characteristics (ANSI Z24.22 - 1957) of ear muffs show some coincidence with physical tests.

A series of nine ear muffs out of eleven were tested under uniform conditions in mines. Three ear muffs were chosen as the best. All three ear muffs are worn behind the head. The ear muff with a support strap, which improves comfort and maintains a good fit during wear, shows the best attenuation. Causes of poor attenuation are numerous: bad mounting of ear muffs on helmets, improper fitting, interference by hair and eye glasses, improper wearing by miners, unsatisfactory enforcement by supervisory personnel, incomplete training of miners, etc.

Results of this research have indicated that none of the ear muffs tested in this study contain all of the characteristics desirable in an ideal unit.

Because of unsatisfactory ear muff attenuation in working conditions (~ 15 dBA) it should be a mandatory requirement that workers wear ear muffs and ear plugs only if the noise level is higher than 105 dBA (various literature recommends 110 dBA).

The key to the solution lies in the following:

- the foreman must be capable of helping and controlling miners in their task of wearing ear muffs properly;
- introduce the program to miners; and
- constant contact must be maintained with manufacturers.

Comprehensive descriptions are provided detailing the experiments upon which the estimates of clamping force, comfort and attenuation are based.

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1. INTRODUCTION

Miners exposed to high noise can become temporarily or permanently deafened. Noise can destroy cells in the inner ear. The resulting damage is usually detected by the change in the threshold of hearing. The major benefit of engineering control through hearing protector usage in Canadian mines is that a number of miners will be protected from a hearing impairment.

The aims of the ear muff studies are outlined in Fig. 1 under three general headings:

(1) Factory procedures;

(2) Laboratory tests in Elliot Lake Laboratory; and

(3) Underground mine.

Results obtained under the three general headings were computed and compared.

Today, problems of noise pollution are widespread, not only in the mining and metallurgical industry, but in many areas of society.

Applications of acoustical theory have become diversified. Because of this, a need has arisen for practical acoustics and noise protection to be synthesized and to offer more practical advice.

This report was written to present basic theory. It can be used as a textbook by those who are not yet familiar with practical and theoretical problems, and it can also be used as a review-book by those more experienced in the subject. The practical part of the report is not limited to attenuation of ear muffs, but also contains much valuable advice for those who work with personal noise protection problems. In this particular field the report goes

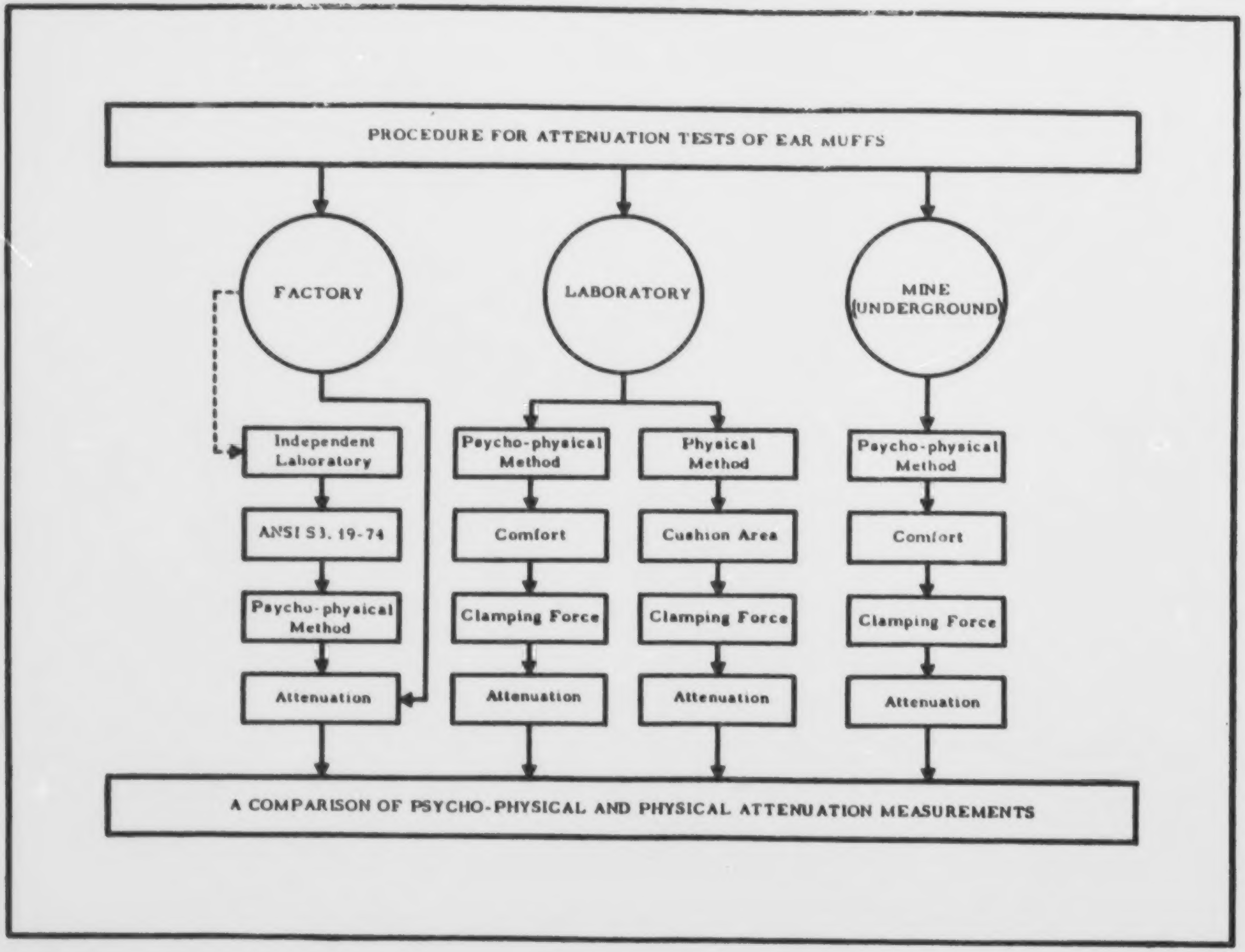
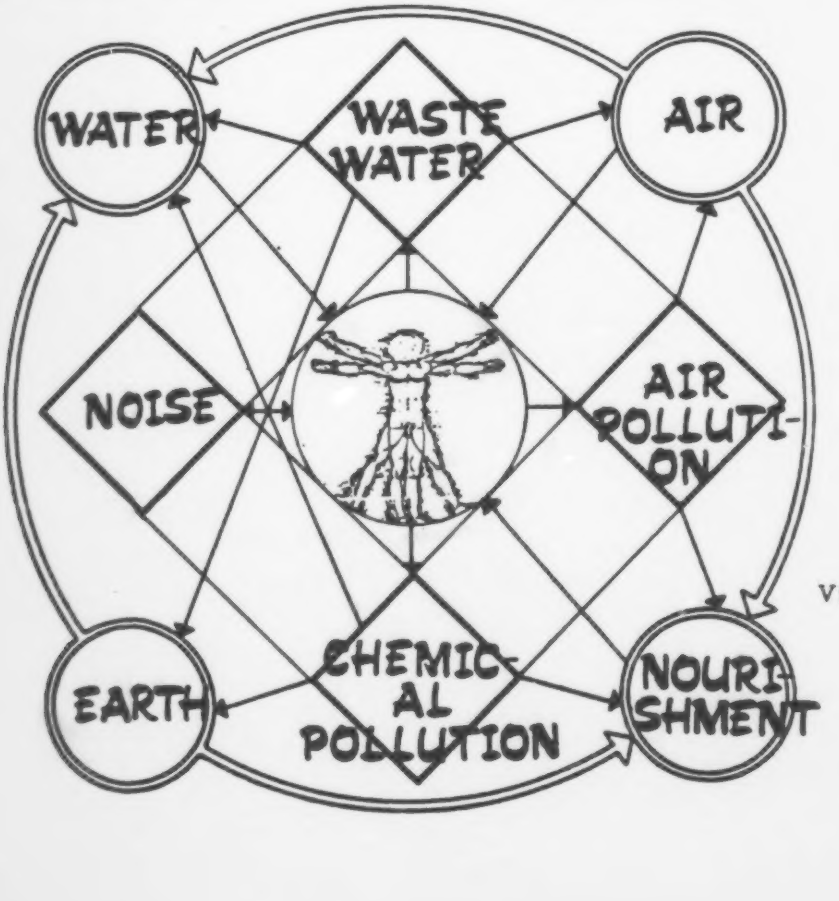

PROCEDURE FOR ATTENUATION TESTS OF EAR MUFFS
FACTORY
LABORATORY
MINE (UNDERGROUND)
Independent Laboratory
ANSI S3. 19-74
Psycho-physical Method
Attenuation
Psycho-physical Method
Comfort
Clamping Force
Attenuation
Physical Method
Cushion Area
Clamping Force
Attenuation
Psycho-physical Method
Comfort
Clamping Force
Attenuation
A COMPARISON OF PSYCHO-PHYSICAL AND PHYSICAL ATTENUATION MEASUREMENTS

Fig. 1: Flow sheet diagram of attenuation test procedure of ear muffs in the Elliot Lake Laboratory.

into some detail. Rather than harm, the readers will have many benefits from the detailed reading. Many of the aspects were not developed historically; they were only described in their existing form. A detailed explanation of all aspects brought up is never lacking so that readers without a technical background in acoustics will be able to understand the content.

To avoid cramming theories into one section the basic ideas of each new theory brought up are immediately described. To avoid repetition many details which are applicable in several parts of the report were only brought up once.

The author did his research by using simplified methods and constructions, which he developed in the Elliot Lake Laboratory.


WATER
WASTE WATER
AIR
NOISE
AIR POLLUTI-ON
EARTH
CHEMIC-AL POLLUTION
NOURI-SHMENT

Vignette

2. GENERAL CONSIDERATIONS

The benefits of reduced noise in mines fall under two categories:

1. The benefits of reduced risk of hearing loss, and
2. The benefits relating to more pleasant working conditions.

Much of the recent information about the dangers of the Canadian mining industry came to light during the Ontario Royal Commission's investigation into the health and safety of mines (1). Following the Commission's recommendations, the Ontario Government brought in Bill 139, which gives workers the right to refuse to work under unsafe conditions. Noise pollution has come to be recognized as a hazardous problem in mines and mills. Surveys of all Ontario industries indicate that the compensation payments awarded in 1976 for noise deafness were around 9 million dollars (Fig. 2) (2).

2. 1. Preventive and Protective Measures

There are three basic elements which should be kept in mind in noise and vibration control: a source, a path, and a receiver. The criteria and exposure limits should be established, supplemented and revised regularly in the light of current knowledge and data. The prevention of occupational hazards in the working environment due to noise and vibration should be kept within limits (3) by:

a) technical measures;

b) supplementary administrative measures, where the technical measures alone do not provide sufficient protection.

Where such measures do not make it possible to bring noise and vibration within the limit:

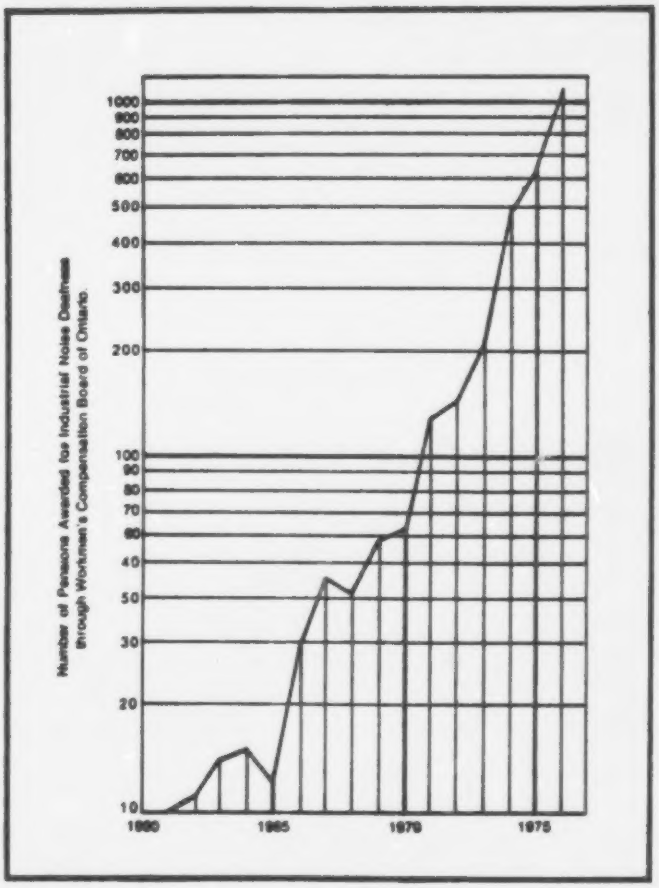


Fig. 2: Noise deafness pensions awarded in Ontario between 1961 and 1976.
Note: The average award in 1976 was $8, 500 (2).

Vignette

a) the employer should supply workers with suitable personal protective equipment and should maintain that equipment; and,

b) the employer should provide appropriate training in the use and maintenance of such equipment, so that workers can comply with relevant instructions.

The codes or regulations should provide for all persons concerned to be adequately:

a) informed of potential occupational hazards in the working environment due to noise and vibration; and,

b) instructed in the measures available for the prevention and control of, and protection against, those hazards.

Measures should be taken to promote research in the field of prevention and control of hazards in the working environment due to noise and vibration. The purpose of this investigation was to systematically assess the noise reduction of ear muffs and to find the best methods possible to control the hazards.

2.2. Existing and Proposed Noise Standards

The noise exposures permitted by the existing OSHA* standard are given in Table 1. When the noise consists of different levels throughout the day, their combined effect is considered as follows:

$$\Sigma C/T = (C_A/8 + C_B/6 + C_C/4 + C_D/3 + C_E/2 + \ldots + C_J/0.25) \qquad \text{(Eq. 1)}$$

where $\Sigma C/T \leq 1$ is the OSHA Mixed Exposure Index, and C_A is the total time the noise level is in band A, C_B is the total time the noise level is in band B, etc.

---

* The Occupational Safety and Health Act (U.S.A.).

The criteria are based on measurements of the equivalent continuous noise level, L_{eq}: provided the noise is not of an "impulsive" nature. Limits are based on tests showing that, for every halving of the duration of exposure, the intensity of exposure can be increased 5 dBA without an increase in the risk of noise-induced hearing losses. The A-weighted reading is used to estimate the probability of hearing damage in industry (Appendix A-3).

TABLE 1

Noise Exposure Limits for a Normal 8-Hour Working Day*

Band	Noise Level (dBA)	Maximum Exposure (h)
A	90	8
B	92	6
C	95	4
D	97	3
E	100	2
F	102	1.5
G	105	1
H	110	0.5
J	115	0.25
	Above 115	None

* U.S. Code of Federal Regulations, Title 29, Section 1910.95.

The National Institute for Occupational Safety and Health (NIOSH) issued a criteria document which called for the eight-hour exposure to be limited to 85 dBA, the four-hour exposure to 90 dBA, etc. (4). Impact noise should not exceed 140 dBC. NIOSH recommended an 85-decibel standard to reduce the chance of workers' hearing loss.

2.3. The Costs of the OSHA and NIOSH Noise Proposals

OSHA commissioned an economic impact study to estimate the cost with the 90-decibel standard (which was not being completely enforced) and the 85-decibel standard. An economic impact study shows U.S. industry's cost of meeting a 90-decibel noise standard would be 13.5-billion U.S. dollars and to comply with the 85-decibel noise standard in five years would require an additional 8-billion U.S. dollars (5). The estimate is based on achieving compliance through engineering alone; with an estimated 155-million U.S. dollars in added cost required annually to maintain monitoring programs and 86-million U.S. dollars for audiometric testing.

To answer the question of how much is needed from Canadian industry to implement and meet 90-decibel and 85-decibel noise standards, a rough estimate can be made using OSHA's U.S. estimates.

Since economic structures in the U.S. and Canada are similar, the estimate was made on the basis of the 1976 census:

	Population
Canada	23,143,000
United States	215,118,000

Estimation* shows that Canadian industry's cost of meeting the 90-decibel noise standard would be 1.7 billion Canadian dollars and 1 billion would be needed to comply with the 85-decibel noise standard. An additional cost of 19 million Canadian dollars would be required annually for permanent monitoring and 10.6 million dollars would be needed annually for audiometric testing.

---

* Mid-Market rates in Canadian Funds, April 10, 1978. Prepared by the Bank of Nova Scotia.

A significant amount of money would have to come from mines, mills and metallurgical plants. In the calculations the inflationary rate of U.S. dollars, which amounts to at least 10% yearly, was not taken into account.

2.4. Working Environment in Canadian Mines

For a better understanding of the noise environment and noise protection in Canadian mines an analysis was made.

1. Noise exposure limits specified in Provincial Governments' regulations are applied in the mining environment. Many machines and installations have noise levels much above the permitted exposure limit and significant reductions have not yet been obtained.
2. A competent authority in the Provincial Government prescribes the frequency, band number for acoustical measurements, and other monitoring conditions for noise in the mining environment. This monitoring is to be carried out by employers even though some mine managements are not always effective in carrying out the task.
3. To satisfy regulations, noise recognized as harmful should be minimized by placing mufflers or exhaust hoses on machinery (Fig. 3). Methods of meeting regulations differ from province to province and mine to mine.
4. The manufacturers have started to make machines and installations that meet noise requirements.
5. Provincial regulations permit the use of personal protective equipment (ear plugs and ear muffs)to meet noise control requirements only if

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June, 1977
EXHAUST AIR HOSE

Fig. 3: A total environment in Canadian mines: roof bolting, good lighting, silencing of exhaust air with hose (~115 dBA), and use of personal protective equipment (ear muffs, glasses, etc.).

---

reduction by technical or administrative means is not technically feasible.

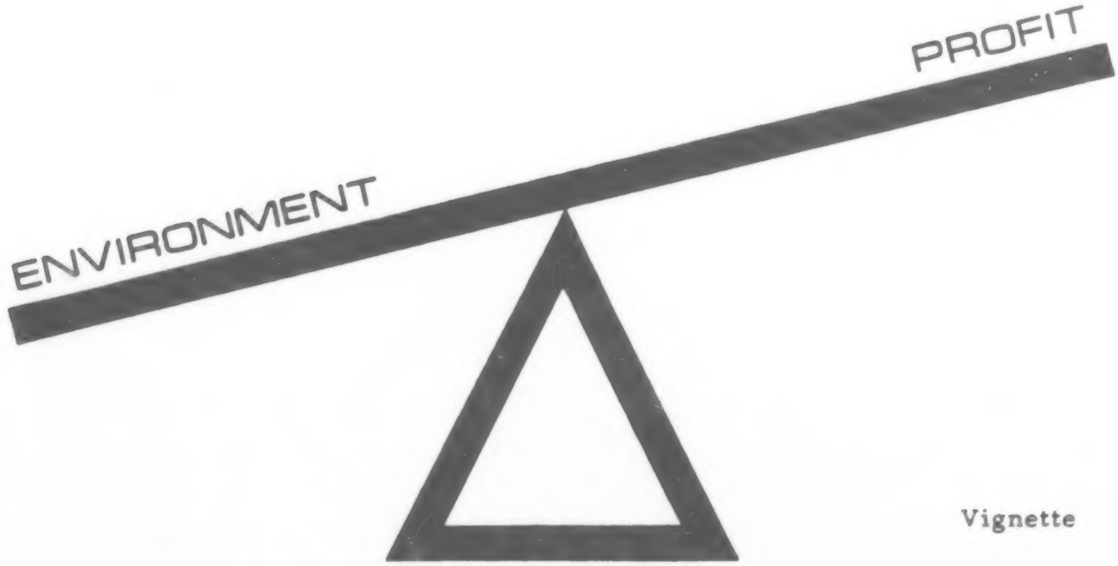
6. In all mines, audiometric tests are required to be carried out by a competent authority:

   a) a pre-assignment examination, and

   b) at suitable periodic intervals.

7. Federal and Provincial Governments promote, assist and stimulate research in the field of prevention and control of noise hazards in the mining environment.
8. Employers' and miners' organizations take action to carry out training and information programs to control noise hazards in the mining environment.

Until technical advances and more stringent regulations are made, along with a larger staff of mine inspectors to enforce them, noise will continue to be a health hazard in the Canadian mining industry. Constant, voluntary use of personal protective equipment, (such as ear plugs and muffs) in all Canadian mines, will guard miners from the threat of hearing loss. Because of this, a new effort has been made to obtain a detailed analysis of ear muffs to improve their application under working conditions.



Vignette

3. PERSONAL EAR PROTECTORS

Often the noise level cannot be reasonably reduced at its source or by the use of acoustical materials and noise barriers. In such cases, some form of ear protection should be considered for those people who are exposed to the noise. There are two types of ear-protection devices; earplugs that fit into the outer ear canal, and muffs that cover the entire ear.

3.1. The Effectiveness of Ear-Protection Devices

The effectiveness of ear-protection devices depends on a number of physical and physiological factors: the nature of the noise, the duration of exposure, attenuation characteristics, and possibly other variables. For a person wearing hearing protection sound energy reaches the inner ear by four different paths:

1) through bone conduction which in effect short circuits the protector;
2) transmitted by vibration of the protective device;
3) by passing through leaks in the protector (which is minimal); and,
4) in acoustic leaks through or around the protective device (Fig. 4).

Ear-protective devices can be divided into four categories:

1) Earplugs (inserts) that fit into the ear canal. There are two types: pre-formed (e.g., moulded rubber, plastic, etc.) and non-preformed (e.g., waxed cotton).
2) Semi-inserts that provide an acoustic seal at the entrance to the ear canal and are supported by headset-type bands.
3) Ear muffs or cushions that cover the external ear. In general, there

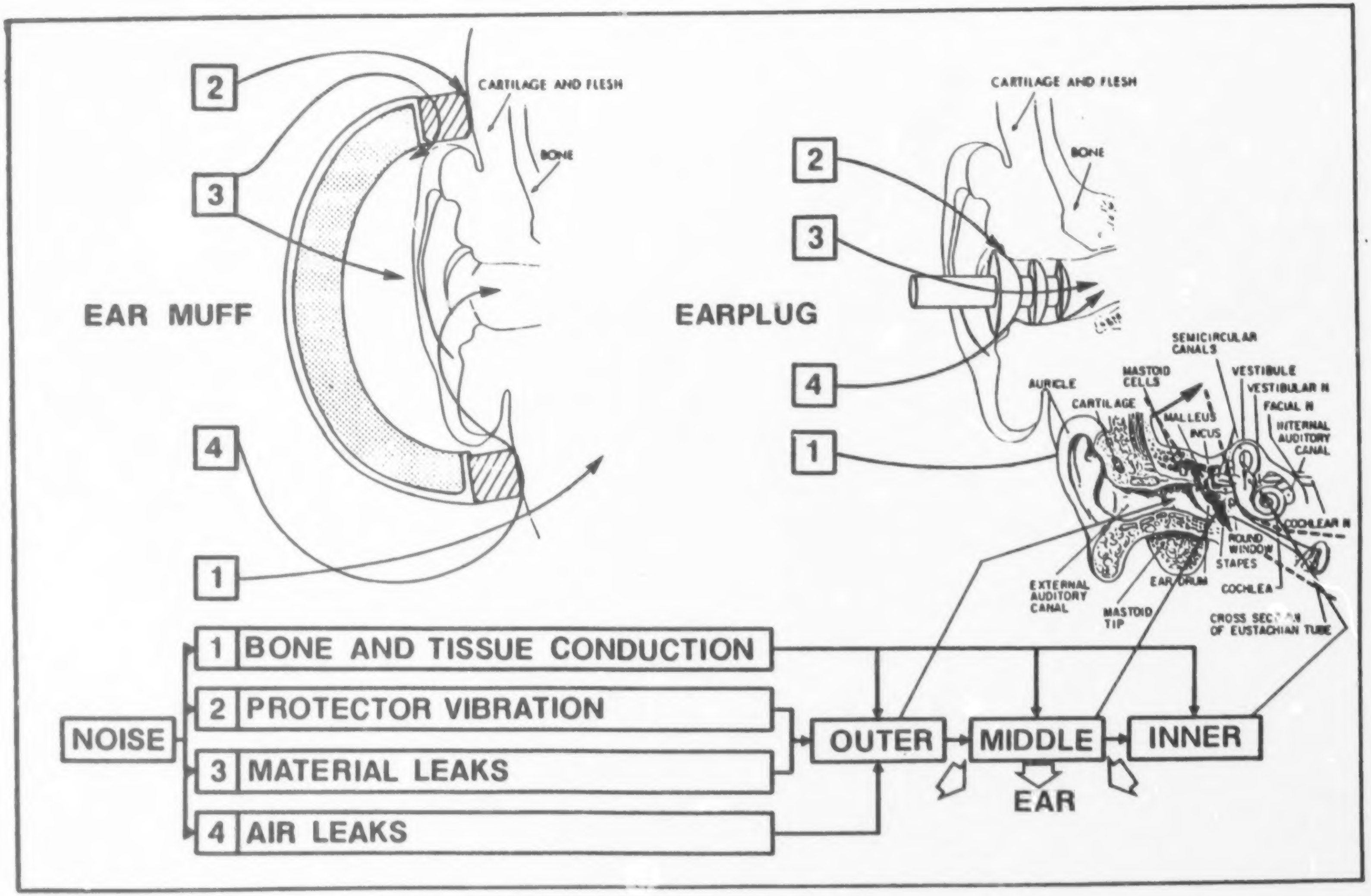

EAR MUFF
EARPLUG
CARTILAGE AND FLESH
BONE
2
3
4
1
AURICLE
CARTILAGE
MASTOID CELLS
SEMICIRCULAR CANALS
VESTIBULE
VESTIBULAR N
FACIAL N
INTERNAL AUDITORY CANAL
MALLEUS
INCUS
COCHLEAR N
ROUND WINDOW
STAPES
COCHLEA
EXTERNAL AUDITORY CANAL
EAR DRUM
MASTOID TIP
CROSS SECTION OF EUSTACHIAN TUBE
NOISE
1 BONE AND TISSUE CONDUCTION
2 PROTECTOR VIBRATION
3 MATERIAL LEAKS
4 AIR LEAKS
OUTER
MIDDLE
INNER
EAR

Fig. 4: Noise transmission paths into the ear when using an ear protector.

are two types:

a) foam cushions that fit around the ear and press against the head; and,

b) fluid-filled cushions similar in size and shape to foam cushions.

They may be held in place by a headband or a helmet.

4) Helmets that fit over the entire head.

Ear protectors must comply with the following basic requirements:

1) To achieve high attenuation of ambient noise. The best ear protectors do not attenuate more than 25 to 30 dB. Attenuation is limited to about 50 dB due to the fact that noise can by-pass the ear-protective device by pick-up and by conduction through the bone of the head (6). Used by themselves earplugs are more effective in attenuation at low frequencies than are ear muffs (Fig. 5). Earplugs and ear muffs can be worn at the same time to provide greater attenuation. The attenuation offered by the combination is less than the sum of the individual attenuations. This phenomenon has not yet been explained. It is believed that a part of the noise enters through the Eustachian tube thus decreasing the earplug's attenuation.

2) An uncomfortable ear protector becomes intolerable after prolonged wear and has to be removed.

3) Ear protectors may have toxic effects on the skin, thus they must be produced so as to facilitate continual use.

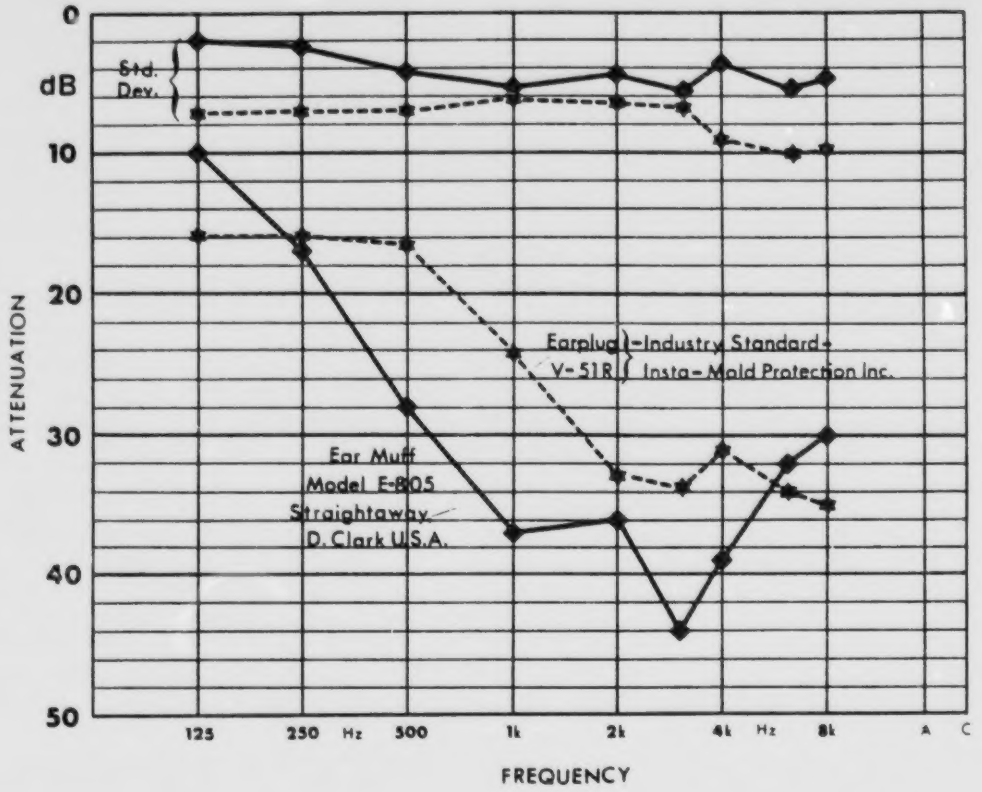


Fig. 5: Attenuation characteristics of two types of ear-protective devices (ANSI* Z24. 22-1957).

4) The ear protector should assure the highest possible speech intelligibility.

5) Ear protectors are effective when used correctly.

6) The durability of ear protectors is a favourable economic factor (especially the expensive ear protectors).

---

* American National Standards Institute.

3. 2. Technical Data of Ear Muffs

Technical data on ear muffs is given in Table 2. Cushion areas, cup volumes and weight vary visibly. The lightest ear muff is No. 5, Model NO NOISE, and the heaviest is No. 7, Model 290-S Safe-T-Earmuff because it has fluid filled cushions. Cups are covered by foam on the inside for two reasons: to increase attenuation because cups leak; and to prevent the formation of standing sound waves (the type of waves that are generated in seashells). In addition to the standard foam pad, Bilson Muffs contain acoustical fibres (Swedish wool) to provide better sound absorption.

Several attempts have been made in the laboratory to increase attenuation by: using metal ear muffs, building in a Grason-Stadler earphone socket, adding one or more Helmholtz resonators, and soft hollow cushions filled with wax (7). The NRC type ear muff was developed at the National Research Council, Ottawa, by E. A. G. Shaw and G. J. Thiessen (8). This device when properly fitted may be worn for many hours without discomfort (9). Constant technical progress of ear muffs, by all manufacturers, is evident.

3. 3. Comfort: One of the Main Requirements of Ear Muffs

The comfort provided by ear muffs depends upon two factors:

1) the ear cushion seal against the head,

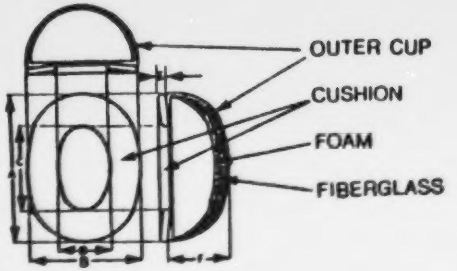
2) the muff design.

3. 3. 1. Ear Cushion Seal Against the Head

The strength of ear cushion seals against the head are a direct consequence of the clamping force, adjustment, softness and weight.

TABLE 2

Characteristics of Ear Muffs Acquired for Testing



No.	Ear Muff	Band	Weight (g)
1	Model 1675, Amer. Optical, U.S.A.	○	183
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.	⊖	284
3	Helmet Muffs -(HF), Bilsom, Sweden.	○	188
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	○	182
5	Model NO NOISE, Hellberg, Sweden.	○	151
6	Model Mark IV, MSA, U.S.A.	○	291
7	Model 290-S Safe-T-Earmuff (gray), Safety Supply Co., Canada.	●	335
8	Model 290-S Safe-T-Earmuff (yellow) Safety Supply Co., Canada.	○	274
9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.	○	278
10	Model E-805 Straightaway, D. Clark, U.S.A.	○	275
11	Sound Barrier EM 152, Willson, U.S.A.	○	295
Σ	Mean	-	248.9
	Std. Dev.	-	60.5

Attenuation (dB)*									
No. 1 to 11	Frequency in Hertz								
	125	250	500	1k	2k	3k	4k	6k	8k
Mean	12.16	17.09	27.8	37.22	36.98	41.07	41.22	35.49	33.53
Std Dev	3.86	2.47	3.09	4.31	3.38	3.9	3.49	5.0	7.36

NOTE:

○ Foam filled cushion

⊖ Foam and air filled cushion

● Fluid filled cushion

No.	Ear Muff	Band	Cross-sectional dimensions (cm)						Area of Cushion (cm²)	Volume of cup (cm³)	Weight (g)				Σ wt (g)	Attenuation (dB)*									
																Characteristic	Frequency in Hertz								
			A	B	C	D	E	F			Cup	Cushion	Foam	Fibre-Glass			125	250	500	1k	2k	3k	4k	6k	8k
1	Model 1675, Amer. Optical, U.S.A.		9.7	9.7	6.5	4.3	1.1	4.2	48.0	180	49.86	13.67	7.61	-	71.14	Measured Std. Dev.	9.7 3.2	16.1 2.5	24.9 2.8	33.9 5.1	34.1 2.0	39.0 5.6	41.0 5.7	33.8 6.6	31.5 5.9
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.		9.5	9.5	6.5	4.2	0.8	4.8	40.0	159	73.45	11.44	3.90	-	88.79	Measured Std. Dev.	5 -	13 -	22 -	31 -	31 -	41 -	36 -	28 -	21 -
3	Helmet Muffs -(HF), Bilsom, Sweden.		10.7	8.0	6.7	4.0	1.0	3.6	35.6	117	51.13	5.79	0.59	2.46	59.97	Measured Std. Dev.	10 -	16 -	30 -	34 -	37 -	41 -	45 -	39 -	36 -
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.		10.5	8.0	6.8	4.1	0.9	3.8	28.5	131	45.30	4.49	1.11	-	50.90	Measured Std. Dev.	11.5 -	16.5 -	26.5 -	36.5 -	38 -	38.5 -	44.5 -	39.5 -	- -
5	Model NO NOISE, Hellberg, Sweden.		10.6	8.0	6.8	4.2	1.0	3.8	28.0	131	42.80	4.43	1.27	-	48.50	Measured Std. Dev.	13.4 3.3	17.3 3.9	26.6 3.0	41.8 3.4	40.7 5.0	45.2 4.6	42.7 5.3	32.6 4.1	29.3 4.7
6	Model Mark IV, MSA, U.S.A.		9.8	8.5	6.5	3.9	1.0	4.5	43.1	158	63.40	10.47	8.07	-	81.94	Measured Std. Dev.	17 2.6	18 2.6	29 3.1	36 3.2	38 4.1	44 7.2	44 4.0	43 4.7	43 5.7
7	Model 290-S Safe-T-Earmuff (gray), Safety Supply Co., Canada		11.0	8.3	6.3	3.6	0.7	4.4	38.7	167	68.64	56.29	2.90	-	127.83	Measured Std. Dev.	18 -	23 -	33 -	44 -	44 -	47 -	45 -	42 -	39 -
8	Model 290-S Safe-T-Earmuff (yellow), Safety Supply Co., Canada		11.0	8.3	6.4	3.7	0.8	4.4	42.5	164	57.02	19.87	4.91	-	81.80	Measured Std. Dev.	18 -	24 -	33 -	44 -	44 -	47 -	45 -	42 -	39 -
9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.		9.4	6.9	6.9	4.6	1.0	4.4	26.7	171	73.94	8.92	3.21	-	86.07	Measured Std. Dev.	12 2.5	17 3.0	30 4.0	35 5.6	35 4.5	36 4.3	37 4.2	32 4.1	30 2.9
10	Model E-805 Straightaway, D. Clark, U.S.A.		9.4	6.9	6.9	4.6	0.9	4.4	24.5	171	76.26	9.05	3.34	-	88.65	Measured Std. Dev.	10 2.0	17 2.6	28 4.3	37 5.4	36 4.8	44 5.6	39 3.6	32 5.4	30 4.9
11	Sound Barrier EM 152, Willson, U.S.A.		11.0	8.2	6.5	4.2	1.0	3.6	42.2	141	52.92	15.92	2.48	-	71.32	Measured Std. Dev.	15 5.2	17 3.9	26 8.0	43 3.6	36 4.9	38 6.6	38 6.0	33 8.3	44 5.3
Σ	Arithmetic Mean of all Ear Muffs		10.24	8.2	6.62	4.13	0.93	4.17	36.16	153.6	59.50	14.58	3.58	2.46	80.12										
	Std. Dev.		0.68	0.86	0.21	0.32	0.12	0.4	7.98	20.4	12.16	14.63	2.46	-	20.35										

* Attenuation characteristic measured in accordance with American National Standard Specification Z24.22-1957. (from Factory Data).

Clamping force (Head force); The clamping force is the force exerted by an ear muff on the skin and it is the most important element of discomfort. Generally, as the clamping force increases, the attenuation offered by an ear muff also increases. If the pressure is strong for a long period of time, the pain may become intolerable. The pressure exerted by ear muffs varies directly with the force applied by their supporting means. The clamping force against the sides of the head varies between 500 and 1000 g wt (10). Pressure limits have not yet been specified for ear muffs, however, pressure against the head is an important aspect. Greatest pressure is needed when the muffs are first put on to ensure a correct fit. Once a good seal has been obtained, the pressure can be decreased. A certain amount of pressure on the skin is necessary to hold the ear muffs in the proper place so that good attenuation is obtained. The contact area between the ear protector and the skin must be set so as not to hinder blood circulation. The clamping force varies and depends on the bizygomatic diameter of the head.

Adjustment: Ear muff adjustment obviously depends upon the shape and dimensions of a worker's head. To fulfil the criterion of a tight fit, the muffs should have the capability of moving the support up and down so as to be parallel with the wearer's ears. To make allowances for everybody's unique head shape, they should also be rotational on a pivot point (Fig. 6). An effective seal inside the cup prevents acoustical leakage around the bearing surface.

Softness: Softness is a prime consideration for ear cushions. Apart from the vital aspect of comfort, an effective noise seal depends upon the cushion

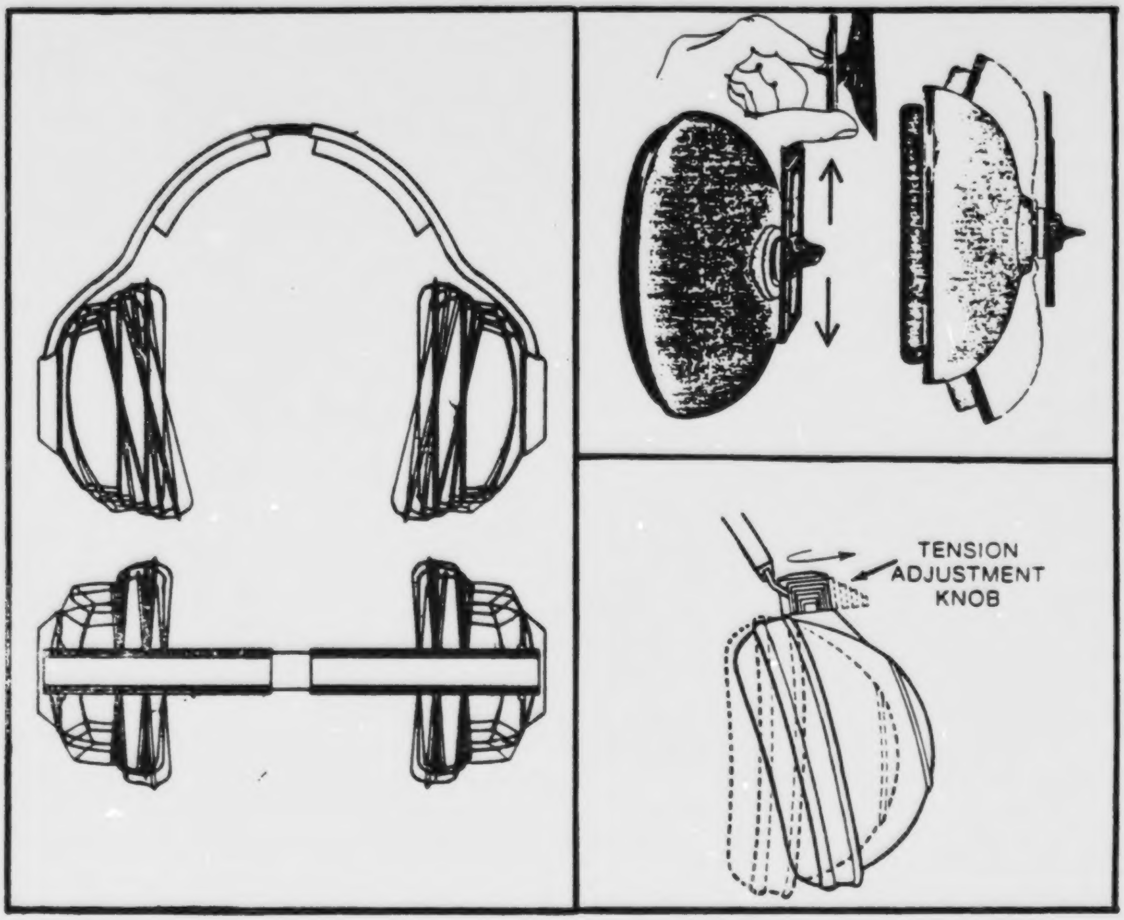


Fig. 6: The muffs should assume the correct angle to the head (11) (12) (13).

---

being soft enough to assume the contours of the head and to fit snugly around the frames of glasses or eyeglass adapters. The comfort collar fits over the ear cushion and provides an agreeable, and hygienic contact surface (Fig. 7).

The comfort collar protects ear cushions from becoming soiled, thus extending their useful life. This is an important economic aspect. Made of soft paper tissue, it absorbs perspiration around the ear and makes ear muffs comfortable to wear (12).

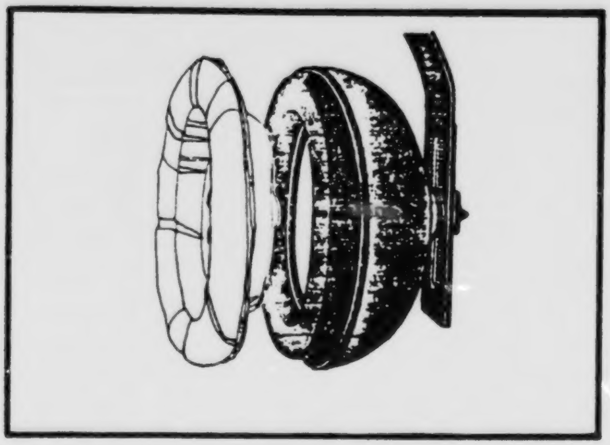


Fig. 7: The comfort collar (12).

Weight: The weight of ear muffs affects comfort greatly because the force of gravity adds to the irritants already present. The total weight of a pair of muffs varies between 151 g and 335 g (Table 2). Their lightness provides comfort even for one full shift of wearing. Heavy muffs become a bother and they increase fatigue for short periods of use. Too low a weight is not good since sound attenuation becomes lower. Lightweight ear muffs maximize the wearer's overall comfort. For comfort, the weight of an ear muff must be limited to approximately 200 grams (14).

3. 3. 2. The Design of Ear Muffs

Designing is an important requirement, especially for things that are worn. Two main factors in the design of ear muffs are: ease of handling, and choice of materials. Ear muffs should be functional and easily handled. Two properties facilitate ease of handling: mechanical simplicity and symmetry (15). Basic principles of mechanical simplicity demand that ear muffs be constructed so simply that instructions for their use are not necessary. The supporting systems, and their muff attachments, are usually so weak that they become bent out of shape. Steel wire supports can be deformed, thus the effect of attenuation is significantly reduced. The fiberglass reinforcement gives the support outstanding flexibility, strength, and resistance to deformation and corrosion. In particular, the connection between the ear muff and the support is very important. If the ear muff is easily rotated around the A-axis, a user is more likely to wear it incorrectly, thus leaving a part of his outer ear uncovered. Such cases are often seen in practice (Fig. 8).

Ear muffs have different degrees of symmetry. Usually ear muffs are symmetrical, except those that are mounted on a helmet. Asymmetrical ear muffs mounted on helmets are a major source of poor attenuation.

3.3.3. Tests of Comfort

Ear muffs must be sufficiently comfortable to be worn for long periods of time, perhaps up to 8 or 10 hours a day. The comfort of ear muffs can be evaluated quantitatively, however, such a test has yet to be devised (15). Simple qualitative inquiries were performed in the Elliot Lake Laboratory to determine whether ear muffs are comfortable.

Male members of the Elliot Lake Laboratory, and several guests, took part in the tests. Women were eliminated from the tests because of the fact that there is no significant participation by them in mining industries (16). Qualitative evaluation was divided into three categories: 1) satisfactory; 2) good; and 3) very good. The experiment was designed so that the differences among age (rows) and qualitative evaluation (columns) represented a major source of variation. Such an arrangement is known as a Latin square (17).

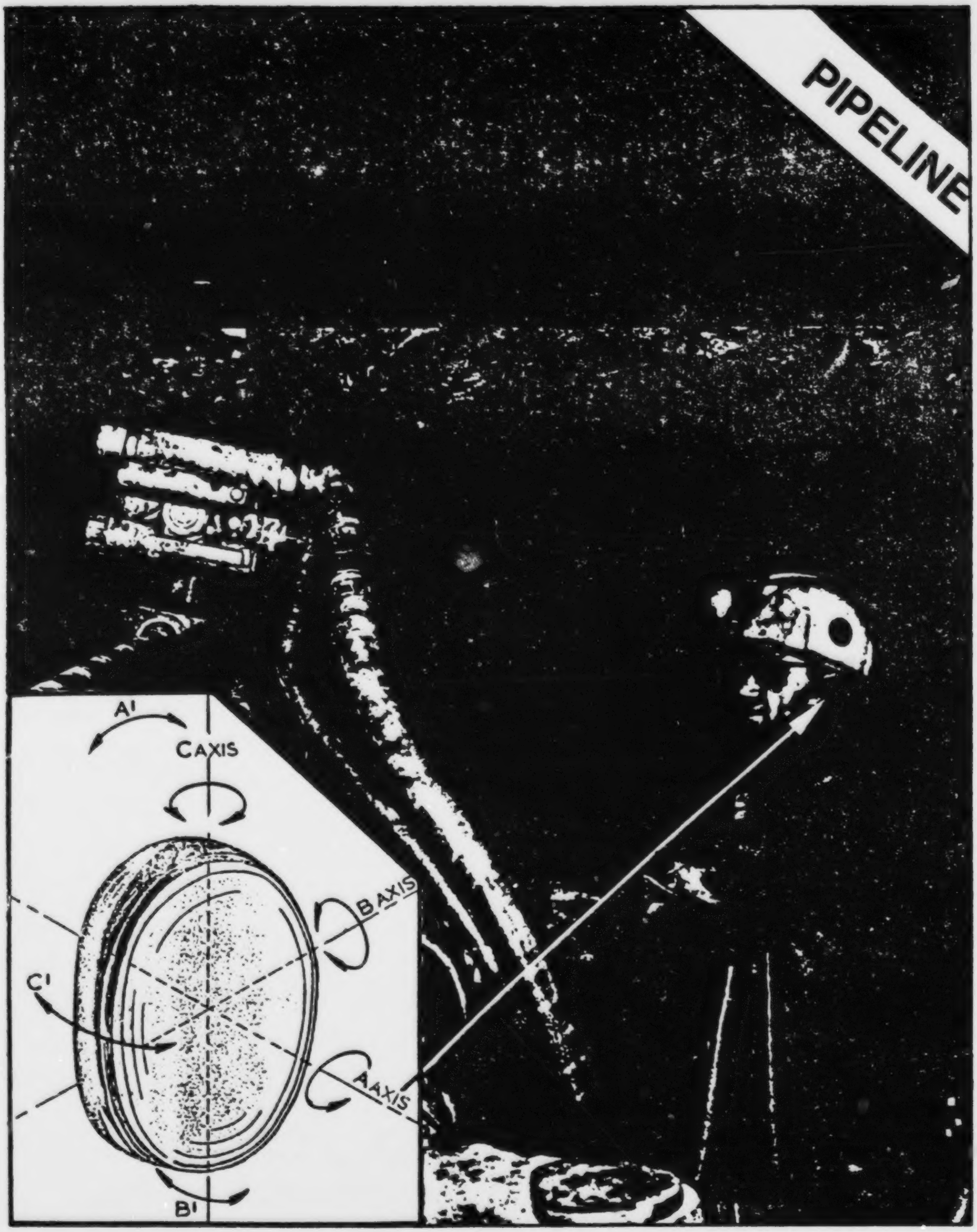

PIPELINE
A'
C AXIS
B AXIS
C'
A AXIS
B'

Fig. 8: The design of this ear muff is not good because it is permitted to rotate around the A-axis. As a direct consequence of this, a part of the outer ear is left uncovered.

We used the method of industrial elimination in the parallel entries. This method is widely used in the selection of industrial products for the elimination of judges whose performance is erratic. A gray No. 7 Safety Supply Co. ear muff, with fluid filled cushions, and a yellow No. 8 Safety Supply Co. ear muff, with sponge filled cushions, were used. Comfort provided by these two ear muffs was relatively equal.

The summary of findings, relating data obtained from 27 subjects, is presented in Table 3. The results of an F-test confirmed a significant difference between muffs. By industrial elimination (muffs No. 7 and No. 8) we can determine which subjects are reliable and which ones are not. Ear muff No. 2 with foam and air filled cushions was chosen as the most comfortable of all. The data obtained from fourteen reliable subjects (mean age is 45.5 ± 3.09 years) show a significant difference between muffs (Table 4). Again, ear muff No. 2 was chosen as the most comfortable of all. From Table 5, no conclusions can be drawn since by industrial elimination, the subjects (mean age is 34.17 ± 2.37 years) were shown to be poor judges. In the analysis, more value was placed on ear muffs with larger cushion areas (Table 2).

3.3.4. Bizygomatic Diameter Survey

The variety of size, shape, and contour of the human head poses a difficult problem to the manufacturer of ear muff protective devices. The major reason for making the bizygomatic diameter survey was to evaluate the clamping force required in ear muff design.

TABLE 3

Comfort Test of Ear Muffs Before Industrial Elimination

	NO.	NUMBER OF SUBJECT	1	2	3	4	5	6	7	★ 8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Σx^2
		EAR MUFF / AGE	19	24	28	28	29	29	30	30	30	30	37	38	38	40	40	42	42	46	46	47	49	52	52	55	57	59	60	
	1	Model 1675, Amer. Optical, U.S.A.	◒	●	●	◒	◒	●	◒	●	●	●	●	◒	◒	◒	●	●	●	◒	●	●	◒	◒	◒	●	◒	○	◒	74
MAXIMUM ▶	2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.	◒	◒	◒	○	○	◒	◒	◒	◒	○	●	◒	●	◒	○	○	◒	◒	◒	●	●	◒	◒	○	◒	◒	○	131
	3	Helmet Muffs -(HF), Bilsom, Sweden.	●	●	◒	●	◒	◒	●	●	○	◒	●	●	●	◒	●	◒	◒	◒	◒	◒	●	●	●	●	●	○	◒	76
	4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	●	○	●	◒	○	●	◒	●	●	◒	●	●	●	●	◒	○	●	●	●	●	◒	◒	●	○	◒	○	●	88
	5	Model NO NOISE, Hellberg, Sweden.	◒	●	●	◒	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	◒	●	◒	◒	●	●	50
	6	Model Mark IV, MSA, U.S.A.	○	○	◒	○	○	◒	●	●	●	●	●	●	◒	●	◒	◒	●	◒	●	◒	●	○	●	◒	◒	◒	◒	100
INDUSTRIAL ELIMINATION	7	Safety Supply Co. (gray), Canada.	○	●	◒	○	●	●	◒	○	○	●	◒	●	◒	●	●	◒	◒	○	◒	●	◒	○	◒	○	◒	◒	◒	119
	8	Safety Supply Co., (yellow), Canada.	◒	●	●	◒	●	◒	○	●	◒	●	◒	◒	●	◒	●	◒	◒	◒	◒	◒	◒	○	◒	○	◒	◒	◒	102
	9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.	◒	○	●	○	●	◒	◒	●	○	●	●	◒	●	◒	◒	○	◒	◒	◒	◒	●	◒	◒	○	◒	○	◒	117
	10	Model E-805 Straightaway, D. Clark, U.S.A.	◒	◒	◒	●	○	●	●	◒	◒	●	◒	◒	◒	◒	●	◒	●	◒	◒	◒	◒	◒	○	○	●	◒	●	99
	11	Sound Barrier EM 152, Willson, U.S.A.	○	◒	◒	◒	●	◒	○	●	○	●	◒	○	◒	●	●	◒	●	◒	○	◒	◒	○	◒	●	◒	○	◒	122
		Σx^2	53	44	29	58	57	29	42	25	52	25	23	34	26	29	28	53	26	43	37	29	29	61	37	65	38	66	40	1078

NOTE: Evaluation
● Satisfactory(1)
◒ Good(2)
○ Very Good(3)

★ Subject No. 8 had extremely opposite judgement of ear muffs 7 & 8 and must be eliminated in further calculations.

THE RESULTS SHOW A SIGNIFICANT DIFFERENCE BETWEEN MUFFS, BY INDUSTRIAL ELIMINATION (MUFFS 7 & 8) WE CAN DETERMINE THE SUBJECTS THAT ARE RELIABLE AND THOSE THAT ARE NOT.

EAR MUFF NO. 2 WAS CHOSEN AS THE MOST COMFORTABLE OVERALL.

{ INDUSTRIAL ELIMINATION ▶ MAXIMUM ◀

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ANOVA        12:46   06/09/77  THURSDAY   T01

N-WAY ANALYSIS OF VARIANCE

FACTOR  LEVEL
  1      27  -  SUBJECTS
  2      11  -  MUFFS

 LINE  |  VARIANCE *   |   SUM OF   | DEGREES OF |   MEAN
  NO.  |  COMPONENT    |   SQUARES  |  FREEDOM   |  SQUARES
   1   |  CMP(     1)  |  29.11784  |    26      |  1.11992
   2   |  CMP(     2)  |  14.50505  |    10      |  1.45050
   3   |  CMP(    12)  | 104.58583  |    260     |  0.40225
       |     TOTAL     | 148.20870  |    296     |

 * E.G., CMP(12) MEANS COMPONENT OF FACTORS 1 AND 2

 GRAND MEAN        1.78451
```

Results of F Test

	Factor	Distribution	
		5% Level of Significance	1% Level of Significance
Muffs	3.61	1.83	2.32
Subjects	2.79	1.50	1.76

```
LINE FOR (A), PLEASE? 1
LINE FOR (B), PLEASE? 3

F-RATIO :     2.78411 (D.F. :  26, 260)
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```
LINE FOR (A), PLEASE? 2
LINE FOR (B), PLEASE? 3

F-RATIO :     3.60595 (D.F. :  10, 260)
```

TABLE 4

Comfort Test of Ear Muffs Using Industrial Elimination

NO.	NUMBER OF SUBJECT	2	5	10	15	16	17	19	21	22	23	24	25	26	27	Σx^2
	EAR MUFF / AGE	24	29	30	40	42	42	46	49	52	52	55	57	59	60	
1	Model 1675, Amer. Optical, U. S. A.	●	◐	●	●	●	●	●	◐	◐	◐	●	◐	○	◐	40
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U. S. A.	◐	○	○	○	○	◐	◐	●	◐	◐	○	◐	◐	○	83
3	Helmet Muffs -(HF), Bilsom, Sweden.	●	◐	◐	●	◐	◐	◐	●	●	●	●	●	○	◐	40
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	○	○	◐	◐	○	●	●	◐	●	◐	○	◐	○	●	69
5	Model NO NOISE, Hellberg, Sweden.	●	○	●	●	●	●	●	●	●	◐	◐	◐	●	●	31
6	Model Mark IV, MSA, U. S. A.	○	○	●	◐	◐	●	●	●	●	○	◐	◐	◐	◐	56
7	Safety Supply Co. (gray), Canada.	●	●	●	●	◐	◐	◐	◐	◐	○	○	◐	◐	◐	54
☒	Safety Supply Co., (yellow), Canada.	●	●	●	●	◐	◐	◐	◐	◐	○	○	◐	◐	◐	54
9	Model E-705 Straightaway Helmet Muffs, D. Clark, U. S. A.	○	●	●	◐	○	◐	◐	●	◐	◐	○	◐	○	◐	67
10	Model E-805 Straightaway, D. Clark, U. S. A.	◐	○	●	●	◐	●	◐	◐	○	◐	○	●	◐	●	56
11	Sound Barrier EM 152, Wilson, U. S. A.	◐	●	●	●	◐	●	○	◐	◐	○	●	◐	○	◐	56
	Σx^2	43	58	24	27	49	22	33	25	33	52	56	34	62	36	552

← 14 SUBJECTS

◀ MAXIMUM

INDUSTRIAL ELIMINATION

NOTE: Evaluation
● Satisfactory(1)
◐ Good(2)
○ Very Good(3)

ANOVA 11:05 06/09/77 THURSDAY T01

N-WAY ANALYSIS OF VARIANCE

FACTOR LEVEL
1 14 — SUBJECTS
2 10 — MUFFS

LINE NO.	VARIANCE * COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
1	CMP(1)	16.94286	13	1.30330
2	CMP(2)	10.54286	9	1.17143
3	CMP(12)	49.05713	117	0.41929
	TOTAL	79.54283	139	

* E.G., CMP(12) MEANS COMPONENT OF FACTORS 1 AND 2

GRAND MEAN 1.84286

RESULTS FROM RELIABLE SUBJECTS SHOW A SIGNIFICANT DIFFERENCE BETWEEN MUFFS. EAR MUFF NO. 2 WAS CHOSEN AS THE MOST COMFORTABLE OVER ALL.

Results of F Test

	Factor	Distribution	
		5% Level of Significance	1% Level of Significance
Muffs	2.79	1.96	2.56
Subjects	3.11	1.80	2.26

LINE FOR (A), PLEASE? 1
LINE FOR (B), PLEASE? 3

F-RATIO : 3.1083 (D.F. : 13, 117)

LINE FOR (A), PLEASE? 2
LINE FOR (B), PLEASE? 3

F-RATIO : 2.7938 (D.F. : 9, 117)

TABLE 5

Comfort Test of Ear Muffs After Industrial Elimination

NO.	NUMBER OF SUBJECT	1	3	4	6	7	9	11	12	13	14	18	20	Σx^2
	EAR MUFF AGE	19	28	28	29	30	30	37	38	38	40	46	47	
1	Model 1675, Amer. Optical, U.S.A.	◑	●	◑	●	◑	●	●	◑	◑	◑	◑	●	33
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.	◑	◑	○	◑	◑	◑	●	◑	●	◑	◑	●	44
3	Helmet Muffs -(HF), Bilsom, Sweden.	●	◑	●	◑	●	○	●	●	●	◑	◑	◑	35
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	●	●	◑	●	◑	●	●	●	●	●	●	●	18
5	Model NO NOISE, Hellberg, Sweden.	◑	●	◑	●	●	●	●	●	●	●	●	●	18
6	Model Mark IV, MSA, U.S.A.	○	◑	○	◑	●	●	●	●	◑	●	◑	◑	43
7	Safety Supply Co. (gray), Canada.	○	◑	○	●	◑	○	◑	●	◑	●	○	●	56
8	Safety Supply Co., (yellow), Canada.	◑	●	◑	◑	○	◑	◑	◑	●	◑	◑	◑	47
9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.	◑	●	○	◑	◑	○	●	◑	●	◑	◑	◑	49
10	Model E-805 Straightaway, D. Clark, U.S.A.	◑	◑	●	●	●	◑	◑	◑	◑	◑	◑	◑	39
11	Sound Barrier EM 152, Willson, U.S.A.	○	◑	◑	◑	○	○	◑	○	◑	●	◑	◑	65
	Σx^2	53	29	58	29	42	52	23	34	26	29	43	29	447

← 12 SUBJECTS

INDUSTRIAL ELIMINATION

◀ MAXIMUM

NOTE: Evaluation
● Satisfactory(1)
◑ Good(2)
○ Very Good(3)

```
ANOVA      13:08   06/09/77  THURSDAY   T01

N-WAY ANALYSIS OF VARIANCE

FACTOR  LEVEL
  1      12 — SUBJECTS
  2      11 — MUFFS

LINE   VARIANCE *     SUM OF      DEGREES OF   MEAN
NO.    COMPONENT      SQUARES     FREEDOM      SQUARES

 1     CMP(    1)     8.81061       11         0.80096
 2     CMP(    2)    13.21212       10         1.32121
 3     CMP(   12)    34.60605      110         0.31460

 :     TOTAL         56.62877      131

* E.G., CMP(12) MEANS COMPONENT OF FACTORS 1 AND 2

GRAND MEAN        1.7197
```

NO CONCLUSIONS CAN BE DRAWN SINCE SUBJECTS WERE SHOWN TO BE POOR JUDGES BY INDUSTRIAL ELIMINATION

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LINE FOR (A), PLEASE? 1
LINE FOR (B), PLEASE? 3

F-RATIO =    2.54597 (D.F. =  11, 110)

LINE FOR (A), PLEASE? 2
LINE FOR (B), PLEASE? 3

F-RATIO =    4.19965 (D.F. =  10, 110)
```

A measurement of maximum distance between the bony structures (zygomatic arches) forward of the ears has been carried out on 27 men in Elliot Lake Laboratory (Fig. 9).

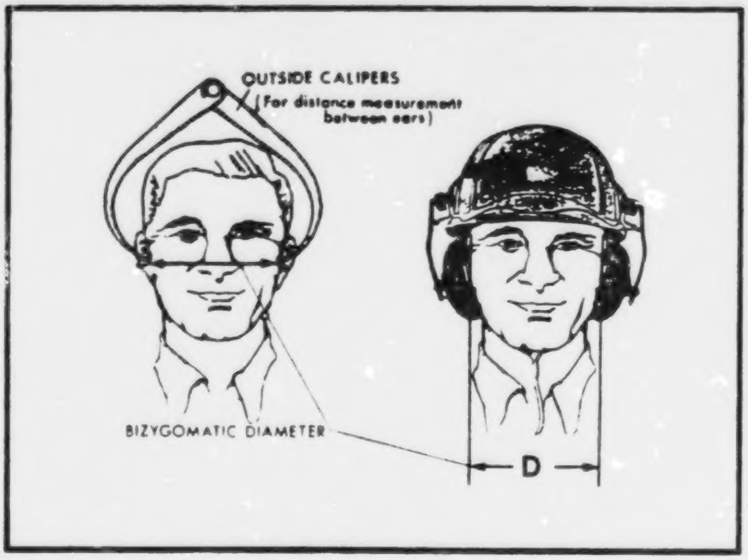


Fig. 9: Bizygomatic diameter measurement with calipers.

The arms of the calipers were pressed against the bone just forward of the ears. The same calipers were used for measurement in mines (Fig. 18).

Statistical analysis of the samples showed that small, but significant differences existed between origin groups (Table 5). The population in the Elliot Lake Laboratory is basically of European origin and is largely made up of people originating from the United Kingdom and Ireland. Subjects were grouped as to origin in the United Kingdom, Con. Europe, Asia, these regions being those represented by the population. The number of people of non-Caucasian origin is very large, ~26 per cent of the population.

In the literature, the volume of bizygomatic diameter data which has been published of Caucasian ethnic origin is relatively small. Comparison of results from Table 6, with other surveys from the literature from Table 7, showed minor differences of no practical importance.

Table 6 and Table 7 show a breakdown of the survey data into United Kingdom origin (Australian, U.S. Air Personnel, U.S. Army) versus Continental European groups. Results from Table 6, showed differences between United Kingdom origin (14.17 ± 0.13) and Continental European groups (14.74 ± 0.28). Also, from Table 7 can be seen similar relations between Australian and United Kingdom-born versus other Foreign-born, and U.S. Air and Army personnel versus NATO Forces. It would appear that the bizygomatic diameters of United Kingdom origin population are slightly smaller, differences being significant between these two groups. The Asian group is too small for statistical comparison. Bizygomatic diameter surveys indicate that differences in ethnic origin may be sufficient to affect clamping force in some instances.

The standard ANSI S3.19-1974 recommended for the measurement of clamping force used hearing protectors separated to a distance of 14.35 cm between earcups (medium head width) (Appendix E-1).

It can be concluded from an examination of the comparative data in byzygomatic diameter surveys that there is a wide range of head size in any single population. However, commercial earmuffs examined will fit this range with corresponding changes in the clamping force.

3.4. Standard Method for the Measurement of the Attenuation of Ear Muffs

Attenuation data are provided by manufacturers who have had their ear muffs tested according to the American National Standards Institute (ANSI)

TABLE 6

Bizygomatic Diameter Surveys in Elliot Lake Laboratory

No.	Population	No. of persons	Means	
			D (cm)	Age (years)
1	Caucasian	20	14.47 ± 0.17	38.70 ± 2.55
2	Non-Caucasian	7	14.13 ± 0.26	43.29 ± 4.43
3	Canadian+	16	14.43 ± 0.16	38.94 ± 3.07
4	Non-Canadian+	11	14.23 ± 0.26	41.27 ± 3.18
5	U.K.++	13	14.17 ± 0.13	37.38 ± 2.90
6	Cont. Europe++	10	14.74 ± 0.28	45.20 ± 4.13
7	Slavic ++	5	15.05 ± 0.50	44.80 ± 4.55
8	Asia+++	7	14.13 ± 0.26	43.29 ± 4.43
9	Age 19 - 39	13	14.05 ± 0.15	30.00 ± 1.48
10	Age 40 - 60	14	14.44 ± 0.19	49.07 ± 1.85
Σ	Canadian	27	14.35 ± 0.14	39.89 ± 2.21

+ 16 Canadian-born versus 11 non-Canadian-born.

++ U.K. origin, Cont. Europe origin, Slavic origin in Cont. Europe

+++ Including Hungary and Finland.

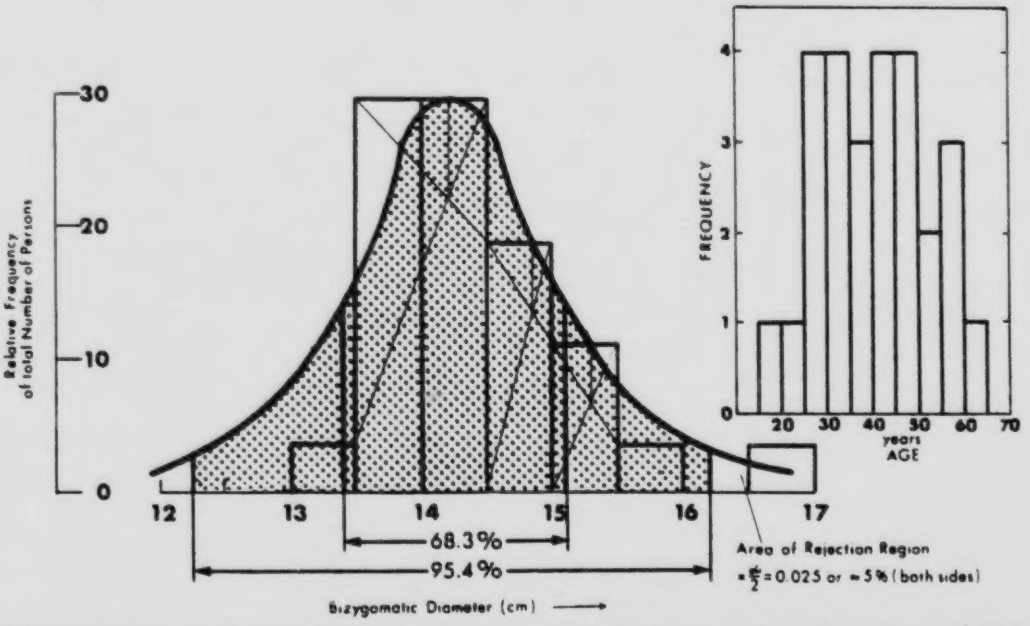


TABLE 7

Bizygomatic Size Surveys from Literature

Mean and Standard Deviations of Australian-Born Versus Non-Australian-Born Subgroups (18)

Parameter	Australian-Born	Non-Australian-Born	U.K.-Born	Other Foreign-born
No. of persons	230	105	53	52
Bizygomatic diameter (cm)	14.04 ± 0.58	14.27 ± 0.6 ($p < 0.01$)	14.06 ± 0.61*	14.48 ± 0.51 ($p < 0.001$)

* Not significant

Mean and Standard Deviation of Other Foreign-Born Subgroups

Parameter	Northern and Central Europe	Southern Europe	Asia	New Zealand
No. of persons	24	13	7	8
Bizygomatic diameter (cm)	14.58 ± 0.55	14.53 ± 0.48	14.26 ± 0.52	14.30 ± 0.35

Bizygomatic Size Surveys, Mean Figures (19) (20) (21)

Parameter	U.S. Air Personnel (1950)	U.S. Army (1945)	NATO Forces (1963)			Australians (1966)	Romanians (1967)
			Turks	Greeks	Italians		
No. of persons	4000	3075 (white) 32 (negro)	915	1084	1358	335	Approx. 3000
Bizygomatic diameter (cm)	14.08	13.98	14.22	14.18	14.31	14.11	13.76

standard Z24. 22-1957 "Method for the Measurement of the Real-Ear Attenuation of Ear Protectors at Threshold". This standard is still in use. Recently a new standard ANSI 3. 19-1974, "Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Ear Muffs", has been published which is a revision of the ANSI Z24. 22-1957 standard. The principal changes are the substitution of narrow bands (third octave bands) of noise instead of discreet tones as the test stimuli, the replacement of an anechoic test room by a reverberant room, and the inclusion of the physical method for production testing and engineering design for ear muffs. This standard is not appropriate to the evaluation of hearing-protective devices designed to operate exclusively against impulsive noise. Apparatus for the measurement of the headband force is described also (Appendix E-1). Test results are expressed by means and standards deviations of the attenuation data for each frequency specified in both standards. Ear muff device force measurement data shall be reported along with real-ear protection data.

Measurements shall be made on not less than ten randomly selected subjects with normal hearing. The test shall be taken with and without the ear protector, on no less than three separate occasions, at each test frequency. The differences with and without protectors are taken to measure the protector's attenuation. Attenuation values are measured under best fitting conditions in the laboratory.

3.5. Attenuation Control of Ear Muffs in the Workplace

The attenuation data, expressed in terms of the means and standard deviations, can be used by the user to evaluate the noise reduction capabilities of the hearing protectors. Calculations involving the direct use of these data are relatively lengthy, and they require that octave band sound pressure level measurement data be recorded from exposure areas. Several methods have been proposed that would simplify the calculations necessary for the user of hearing protectors. Evaluation through four methods has been proven:

a) One proven theoretical method for calculating a single number rating of attenuation efficiency of hearing protectors; and

b) Three proven approximate methods which tend to considerably over or under-estimate the attenuation produced by hearing protectors. Their information value is not equivalent to that of precise calculation.

Application of a safety coefficient could improve the reliability of approximate methods.

3.5.1. Noise Reduction Evaluation - Theoretical Method

The noise reduction rating of hearing protectors is based on the transmission loss in nine octave band centre frequencies (Hz) (22). The method involves calculating the noise reduction in the A-weighted sound level as follows (Table 8):

1) Calculate the A-weighted sound level (L_1) of the untreated noise from its octave band centre frequency (Hz);

TABLE 8

A Method for Calculating a Single Number Rating of Noise Attenuating Ear Muffs (see Table 19)

Frequency (Hz)	Noise Level of Jumbo (Three Drills) (dB)	Attenuation ANSI Z24. 22-1957 (dB)	Treated Noise Level (dB)
31.5	89	-	-
63	100	-	-
125	109	9.7	99.3
250	109	16.1	92.9
500	109	24.9	84.1
1000	107	33.9	73.1
2000	108.5	34.1	74.4
4000	109.5	38.5	71
8000	106	32.7	73.3

Step 1: The A weighted sound level (L_1) of the untreated noise in dBA.

Frequency (Hz)	Noise Level of Jumbo (Three Drills) (dB)	A-Weighting (dB)	Weighted Level (dB)	Antilog (Weighted Level / 10)
31.5	89	-39.4	49.6	0.0009 x 10^8
63	100	-26.2	73.8	0.2399 x 10^8
125	109	-16.1	92.9	19.4984 x 10^8
250	109	- 8.6	100.4	109.6478 x 10^8
500	109	- 3.2	105.8	380.1894 x 10^8
1000	107	0	107	501.1872 x 10^8
2000	108.5	+ 1.2	109.7	933.2543 x 10^8
4000	109.5	+ 0.9	110.4	1096.4782 x 10^8
8000	106	- 1.2	104.8	301.9952 x 10^8
			Σ	3342.4913 x 10^8

$L_1 = 10 \log \Sigma = 115.24$ dBA

Step 2: The A-weighted sound level (L_2) of the treated noise in dBA.

Frequency (Hz)	Treated Noise Level (dB)	A-Weighting (dB)	Weighted Level (dB)	Antilog (Weighted Level / 10)
125	99.3	-16.1	83.2	2.0893 x 10^8
250	92.9	- 8.6	84.3	2.6915 x 10^8
500	84.1	- 3.2	80.9	1.2303 x 10^8
1000	73.1	0	73.1	0.2042 x 10^8
2000	74.4	+ 1.2	73.2	0.2049 x 10^8
4000	71	+ 0.9	70.1	0.1023 x 10^8
8000	73.3	- 1.2	72.1	0.1622 x 10^8
			Σ	6.6847 x 10^8

$L_2 = 10 \log \Sigma = 88.25$ dBA

Noise Reduction $= L_1 - L_2 = 26.99$ dBA

2) Calculate the A-weighted sound level (L_2) of the treated noise from its octave band centre frequency (Hz) components, which are the respective octave band attenuations provided by the hearing protector; and

3) Subtract L_2 from L_1:

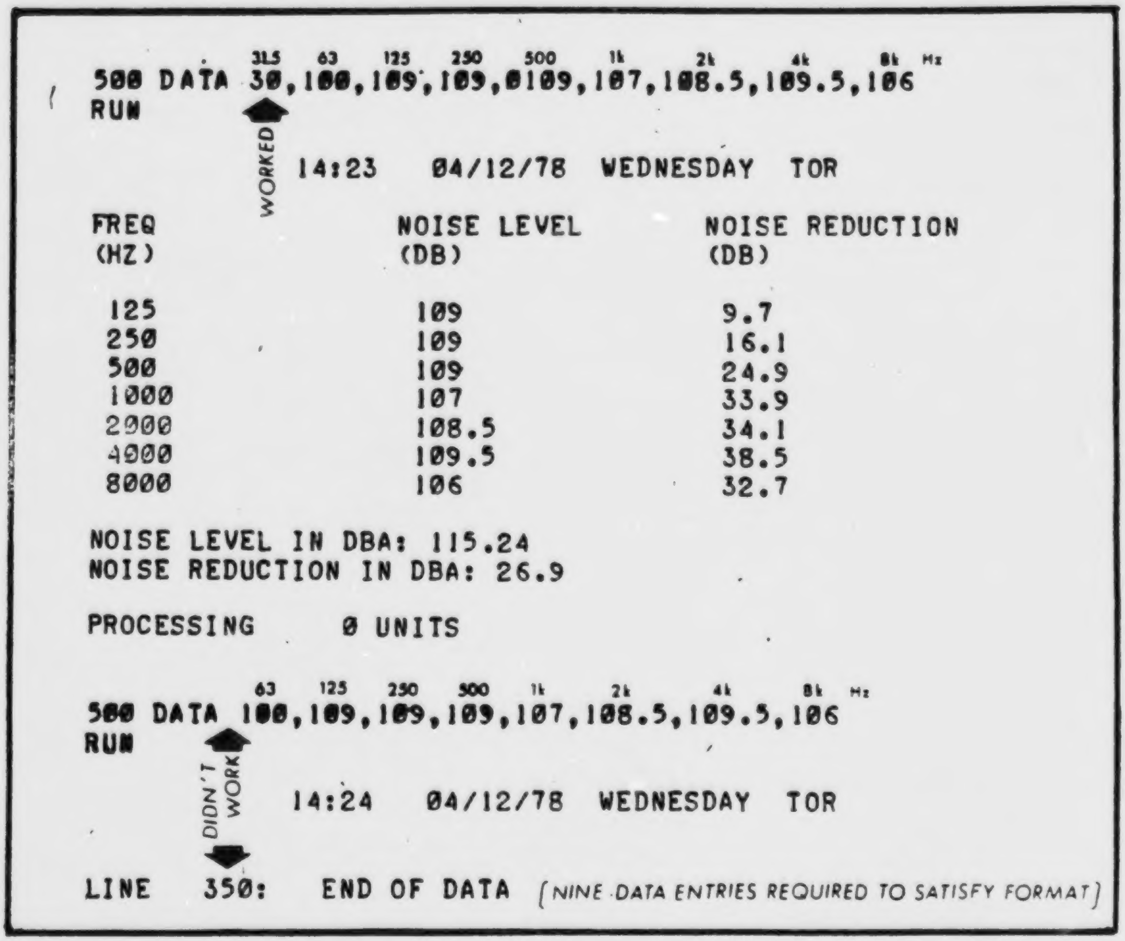
Theoretical Noise Reduction (dBA) = $L_1 - L_2$.

A computer program is included to calculate the 26.9 dBA noise reduction in the same way that it was calculated by long hand (Appendix A-1). The data format of the program did not have to be modified when the untreated noise was not measured in the first two octave bands (31.5 and 63 Hz). At octave band frequencies of 31.5 Hz and 63 Hz an entry must be made of a very small number which has no influence on the evaluation of noise levels in dBA (Fig. 10). Difference in noise between 125 Hz and 31.5 Hz, or 63 Hz should be less by 20 dB (compare Appendix A-1 with Fig. 10).

The proposed method is not limited to ear protectors. It can be applied to determine the noise reduction of acoustical enclosures, the installation of acoustical absorptive material in a particular room, etc.

3.5.2. Approximate Methods for Calculating Noise Reduction

Published references, such as those of the American National Standards Institute and the American National Institute of Occupational Safety and Health (NIOSH), provide information for selecting hearing-protective devices (23) (24). A proposed regulation requires that any hearing protector used by an employee shall reduce the effective noise level to less than 90 dBA (OSHA). This regulation suggests three methods for



```
500 DATA 30,100,109,109,0109,107,108.5,109.5,106
RUN

            14:23   04/12/78  WEDNESDAY  TOR

FREQ                NOISE LEVEL         NOISE REDUCTION
(HZ)                (DB)                (DB)

 125                 109                  9.7
 250                 109                 16.1
 500                 109                 24.9
 1000                107                 33.9
 2000                108.5               34.1
 4000                109.5               38.5
 8000                106                 32.7

NOISE LEVEL IN DBA: 115.24
NOISE REDUCTION IN DBA: 26.9

PROCESSING     0 UNITS

500 DATA 100,109,109,109,107,108.5,109.5,106
RUN

            14:24   04/12/78  WEDNESDAY  TOR

LINE   350:   END OF DATA
```

31.5
63
125
250
500
1k
2k
4k
8k
Hz
WORKED
DIDN'T WORK
[NINE DATA ENTRIES REQUIRED TO SATISFY FORMAT]

Fig. 10: Computer printout illustrating results from calculations; with a frequency of 31.5 Hz and only 30 dB, and without this frequency. (Compare with Appendix A-1).

---

determining the noise reduction (R), given in sections 1, 2 and 3 below.

The determination of R is based on a knowledge of the attenuation of the ear protectors in octave bands and an A-slow sound level analysis of the noisy environment. The pure tone attenuation vs. frequency characteristics of the ear protector (normally supplied by the manufacturer) should be determined in accordance with standards ANSI Z24.22-1957 or ANSI S3.19-1974. The standards prescribe the bands with the following centre frequencies: 125, 250, 500, 1000, 2000, 3000 (3150), 4000, 6000 (6300) and 8000 Hz.

We will also assume that the 4000 Hz octave band attenuation level can be obtained by averaging the pure tone attenuation levels at 3000 and 4000 Hz, and that the 8000 Hz octave band attenuation level can be obtained by averaging the pure tone attenuation levels at 6000 and 8000 Hz.

Method 1

The procedure to determine the dBA reduction (R):

$$R = L_A - 10 \log S \qquad \text{(Eq. 2)}$$

where R = dBA - reduction factor

L_A = workplace dBA noise level

$$\begin{aligned} S = {} & \text{antilog}\,[0.1 \times (L_1 - Q_1)] + \text{antilog}\,[0.1 \times (L_2 - Q_2)] \\ & + \text{antilog}\,[0.1 \times (L_3 - Q_3)] + \text{antilog}\,[0.1 \times (L_4 - Q_4)] \\ & + \text{antilog}\,[0.1 \times (L_5 - Q_5)] + \text{antilog}\,[0.1 \times (L_6 - Q_6)] \\ & + \text{antilog}\,[0.1 \times (L_7 - Q_7)] \end{aligned}$$

where L_1, L_2, ..., L_7 denote the octave band levels in dB at 125, 250, 500, 1000, 2000, 4000, and 8000 Hz respectively, and for the evaluation of the pure tone attenuation supplied by the manufacturer:

Let Q_1, Q_2, ..., Q_7 be defined (in dB) as follows:

Q_1 = attenuation at 125 Hz, plus 16.1 dB, minus 2 x (standard deviation)

Q_2 = attenuation at 250 Hz, plus 8.6 dB, minus 2 x (standard deviation)

Q_3 = attenuation at 500 Hz, plus 3.2 dB, minus 2 x (standard deviation)

Q_4 = attenuation at 1000 Hz, minus 2 x (standard deviation)

Q_5 = attenuation at 2000 Hz, minus 1.2 dB, minus 2 x (standard deviation)

Q_6 = average of attenuation at 3000 and 4000 Hz, minus 0.9 dB, minus standard deviation at 3000 Hz, minus standard deviation at 4000 Hz

Q_7 = average of attenuations at 6000 and 8000 Hz, minus standard deviation at 6000 Hz, minus standard deviation at 8000 Hz.

The numbers +16.1, + 8.6, +3.2, 0, - 1.2, - 0.9 represent the A-weighting relative response at the indicated octave band centre frequencies.

Evaluation:

Ear muff Model 1675, American Optical, U.S.A. was used in a working area with a noise level of 115.24 dBA (Jumbo-three drills) and octave band noise levels of:

125	250	500	1000	2000	4000	8000 Hz
109	109	109	107	108.5	109.5	106 dB

and the ear muff had the following attenuation characteristics (ANSI Z24.22-1957):

	125	250	500	1000	2000	3000	4000	6000	8000	Hz
Mean Attenuation	9.7	16.1	24.9	33.9	34.1	36.0	41.0	33.8	31.5	dB
Std. Dev.	3.2	2.5	2.8	5.1	2.9	5.6	5.7	6.6	5.9	
						38.5		32.65		

The "Q" and "L -Q" values in S are:

$Q_1 = 9.7 + 16.1 - (2 \times 3.2) = 19.4 \quad (L_1 - Q_1) = 109 - 19.4 = 89.6$

$Q_2 = 16.1 + 8.6 - (2 \times 2.5) = 19.7 \quad (L_2 - Q_2) = 109 - 19.7 = 89.3$

$Q_3 = 24.9 + 3.2 - (2 \times 2.8) = 22.5 \quad (L_3 - Q_3) = 109 - 22.5 = 86.5$

$Q_4 = 33.9 - (2 \times 5.1) = 23.7 \quad (L_4 - Q_4) = 107 - 23.7 = 83.3$

$Q_5 = 34.1 - 1.2 - (2 \times 2.9) = 27.1 \quad (L_5 - Q_5) = 108.5 - 27.1 = 81.4$

$Q_6 = 38.5 - 0.9 - 5.6 - 5.7 = 26.3 \quad (L_6 - Q_6) = 109.5 - 26.3 = 83.2$

$Q_7 = 32.7 + 1.2 - 6.6 - 5.9 = 21.4 \quad (L_7 - Q_7) = 106 - 21.4 = 84.6$

Applying the formula for the dBA reduction factor,

$$R = L_A - 10 \log S$$

where $L_A = 115.24$ dBA

and $S = \text{antilog}\,(0.1 \times 89.6) + \text{antilog}\,(0.1 \times 89.3)$

$+ \text{antilog}\,(0.1 \times 86.5) + \text{antilog}\,(0.1 \times 83.3)$

$+ \text{antilog}\,(0.1 \times 81.4) + \text{antilog}\,(0.1 \times 83.2)$

$+ \text{antilog}\,(0.1 \times 84.6)$

$= 912,010,836 + 851,138,037 + 446,683,590$

$+ 213,796,208 + 138,038,427 + 208,929,612$

$+ 288,403,151$

$= 3,058,999,861$

$R = 115.24 - 10 \log (3,058,999,861) = 115.24 - 94.86$

$= 20.38$ dBA

The effective level is:

$$L_A - R = 115.24 - 20.38 = 94.86 \text{ dBA}$$

This calculation should be simplified as shown in Table 9.

Discussion:

The R factor calculated by this method incorporates an adjustment to account for statistical variation. It is the most precise method.

Ancient Egypt's tool
in the modern mining
environment

Vignette

TABLE 9

Noise Reduction Calculation Example

Octave Band Measurements		Modifying Factors for Noise Reduction			
Centre Frequency	SPL dB B	A-Weighting Factor A	2σ C	Ear Muff Attenuation D	Resultant Noise at Ear B+A+C-D
125	109	-16.1	6.4	9.7	89.6
250	109	- 8.6	5	16.1	89.3
500	109	- 3.2	5.6	24.9	86.5
1000	107	0	10.2	33.9	83.3
2000	108.5	+ 1.2	5.8	34.1	81.4
4000	109.5	+ 0.9	11.3	38.5	83.2
8000	106	- 1.2	12.5	32.7	84.6
	115.24 dBA*			$10 \log_{10}$ Sum =	94.86dBA

Noise Reduction Factor = 115.24 - 94.86 = 20.38 dBA
* See Program in Appendix A-2.

Method 2

This method has been formulated concisely by the Recommended Noise Standard, and includes subtraction of 10 dB to account for possible noise spectrum irregularities and noise leakage which might be caused by long hair, safety glasses, head movement, etc. The procedure to determine dBA (R):

$$R = L_A - 10 \log S - 10.0 \qquad \text{(Eq. 3)}$$

where R = dBA - reduction factor

L_A = workplace dBA noise level

10.0 is the correction factor

$S = \text{antilog}\,[0.1 \times (L_1 - Q_1)] + \ldots + \text{antilog}\,[0.1 \times (L_7 - Q_7)]$

where L_1, L_2, ..., L_7 denote octave band levels in dB at 125, 250, 500, 1000, 2000, 4000, and 8000 Hz respectively, and Q_1, Q_2, ..., Q_7 denote the attenuation data supplied by the manufacturer including the A-weighting network at the indicated octave band centre frequencies.

Evaluation:

The same ear muff and the same working area as in Method 1 was used:

$Q_1 = 9.7 + 16.1 = 25.8$ $\qquad (L_1 - Q_1) = 109 - 25.8 = 83.2$

$Q_2 = 16.1 + 8.6 = 24.7$ $\qquad (L_2 - Q_2) = 109 - 24.7 = 84.3$

$Q_3 = 24.9 + 3.2 = 28.1$ $\qquad (L_3 - Q_3) = 109 - 28.1 = 80.9$

$Q_4 = 33.9 = 33.9$ $\qquad (L_4 - Q_4) = 107 - 33.9 = 73.1$

$Q_5 = 34.1 - 1.2 = 32.9$ $\qquad (L_5 - Q_5) = 108.5 - 32.9 = 75.6$

$Q_6 = 38.5 - 0.9 = 37.6$ $\qquad (L_6 - Q_6) = 109.5 - 37.6 = 71.9$

$Q_7 = 32.7 + 1.2 = 31.5$ $\qquad (L_7 - Q_7) = 106 - 31.5 = 74.5$

Applying the formula for the dBA reduction factor,

$$R = L_A - 10 \log S - 10.0$$

where $L_A = 115.24$ dBA

and S = antilog (0.1 x 83.2) + antilog (0.1 x 84.3)
+ antilog (0.1 x 80.9) + antilog (0.1 x 73.1)
+ antilog (0.1 x 75.6) + antilog (o.1 x 71.9)
+ antilog (0.1 x 74.5)
= 208,929,612 + 269,153,479 + 123,026,877
+ 20,417,379 + 36,307,805 + 15,488,166
+ 28,183,829 = 701,507,147

$$R = 115.24 - 10 \log (701,507,147) - 10.0$$
$$= 115.24 - 88.46 - 10.0 = 16.78 \text{ dBA}$$

The effective dBA level is

$$L_A - R = 115.24 - 16.78 = 98.46 \text{ dBA}$$

Discussion:

This method is similar to Method 1 except that 2σ (2 x standard deviation) is not subtracted from Q. This method includes subtraction of 10 dB to account for possible noise spectrum irregularities and noise leakage which might be caused by long hair, safety glasses, head movement, etc.

Method 3

If the octave band levels of the noise are not known, then the dBA reduction R may be computed simply:

$$R = - 10 \log S - 3.0 \qquad \text{(Eq. 4)}$$

where R = dBA - reduction factor

$S = \text{antilog}(-0.1 \times Q_1) + \ldots. + \text{antilog}(-0.1 \times Q_7)$

3.0 is the correction factor

Evaluation:

The same ear muff was used as in Method 1 and Method 2. The "Q" value is the same as in Method 2. Applying the formula for the dBA reduction factor:

$$R = - 10 \log S - 3.0$$

where $S = \text{antilog}(-2.58^*) + \text{antilog}(-2.47) + \text{antilog}(-2.81)$

$+ \text{antilog}(-3.39) + \text{antilog}(-3.29) + \text{antilog}(-3.76)$

$+ \text{antilog}(-3.15)$

---

* $\text{antilog}(-2.58) = \text{antilog}(7.42 - 10)$

$= \text{antilog } \bar{3}.42$

$$= 0.00263 + 0.00339 + 0.00155 + 0.00014$$

$$+ 0.00051 + 0.00017 + 0.00071$$

$$= 0.00937$$

$$R = -10 \log 0.00937 - 3.0 = 20.28 - 3.0 = 17.28 \text{ dBA}$$

The effective dBA level is:

$$L_A - R = 115.24 - 17.28 = 97.96 \text{ dBA}$$

Discussion:

This calculation is approximate, and is based upon the assumption that the octave band levels are equal. For most types of noise it will give results close to those obtained by the more accurate Method 2, above.

3.5.3. Comparison of Calculation Methods

Several methods were developed to determine dBA reduction (R) for ear protectors. J. Botsford's method is based on "sound level conversion" (24). The reduction factor (R) is computed by using the attenuation data of a hearing protector and a single noise spectrum, which is composed of equal sound pressure levels for the median octave bands found in major industries in the U.S.A.

Three computational approximate methods show three different R factors for the same ear muff (Table 10).

Fairly close agreement was shown between the Jumbo operator (measured - 18.6 dBA) result and the Method 3 - 17.28 dBA result. Results from the 2nd Method are similar to those of the 3rd Method. In this report, only the theoretical method of noise reduction (attenuation) was calculated because of two reasons:

TABLE 10

Comparison of Noise Reduction Factors of Ear Muff, Model 1675, American Optical, U.S.A., by Different Evaluation Methods

Operator	Noise Reduction - dBA				
	Measured	Approximate methods			Theoretical Method
		1	2	3	
Jumbo (Three Drill)	18.6	20.38	16.78	17.28	26.9
Drill Hydrofore	12.6	22.71	18.71	17.28	28.8
Jaw Crusher	15	21.16	17.65	17.28	27.7

1) From theoretical noise reduction results, the approximate noise reduction can be calculated by using Method 1 (6 dBA are subtracted from the theoretical attenuation) and Method 2 and 3 (10 dBA are subtracted from the theoretical attenuation).

2) Results of the theoretical noise reduction can be easily compared with EPA's* proposed hearing protector regulations (25).

EPA established the framework for labeling hearing protector products (Fig. 11). The label on the product will bear a number from 0 - 31. The higher the number, the greater the product's effectiveness in attenuating noise. Regulations for these products will be developed from the proposed General Provisions and Hearing Protector Regulations and will be announced in the Federal Register.

By analyzing the results from our measurements, we see that, in practice, the greatest noise reduction is not always given by ear muffs

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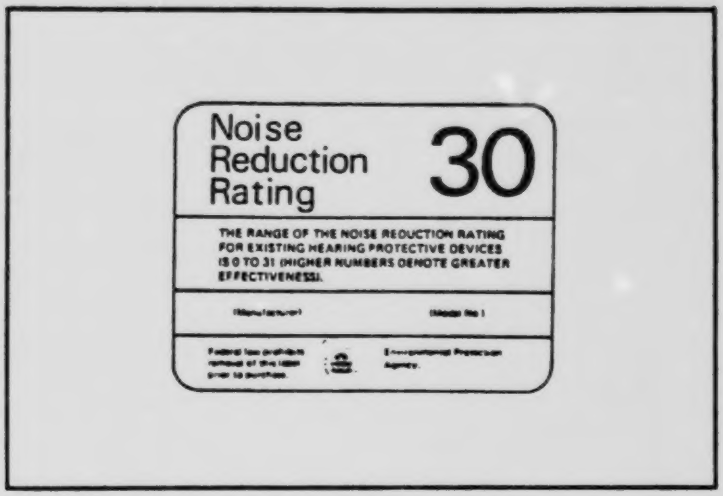
* Environmental Protection Agency.



Noise Reduction Rating 30

THE RANGE OF THE NOISE REDUCTION RATING FOR EXISTING HEARING PROTECTIVE DEVICES IS 0 TO 31 (HIGHER NUMBERS DENOTE GREATER EFFECTIVENESS).

Fig. 11: Sample of proposed label.

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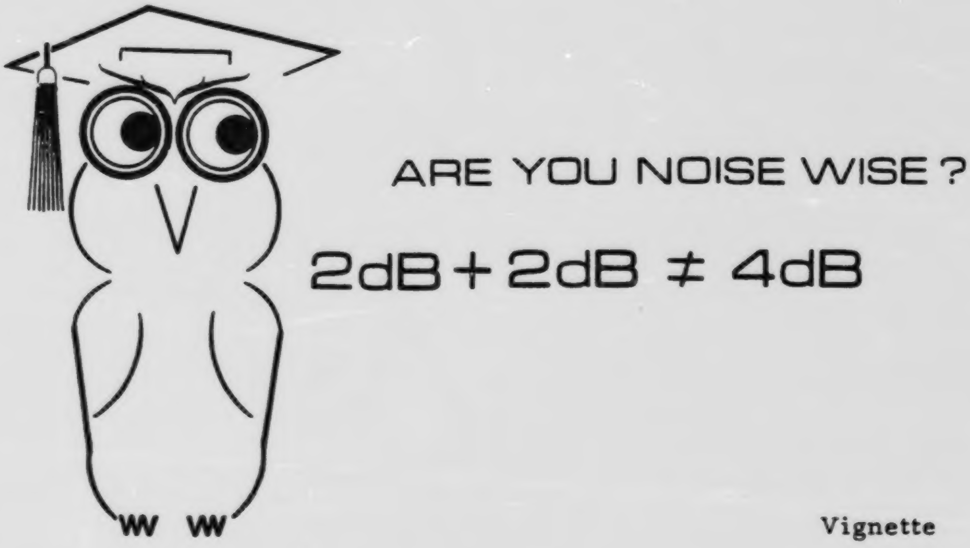
which have the best attenuation characteristics. Many other factors affect the increase or decrease of attenuation.

To investigate the differences between laboratory test attenuation data, a new field test method for ear muffs has been developed in the Elliot Lake Laboratory.



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4. LABORATORY TESTS

Measurements of ear muff attenuations have been made using two methods:

1. Psychophysical method using human heads by static range-of-movement:
    a) Movement of the joint of the neck in normal position. Subject used glasses and adaptors.
    b) Movement of the joint of the neck flexion (dorsal and ventral) and neck rotation (right and left). Subject used glasses.
2. Physical method using apparatus for determining the efficiency of cup cushions.

These tests were made to provide performance data for eleven models of ear muffs under testing procedures established in the Elliot Lake Laboratory (Table 2):

No. 1: Model 1675, Amer. Optical, U.S.A.: often used in mills and workshops;

No. 2: Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.; It is used in mines, but is no longer in production;

No. 3: Helmet Muffs - (HF), Bilsom Sweden; it is used in workshops and mines;

No. 4: Model NO NOISE Helmet Muffs, Hellberg, Sweden; it is used in mines;

No. 5: Model NO NOISE, Hellberg, Sweden; it is used in mines;

No. 6: Model Mark IV, MSA, U.S.A.; it is used in mines and mills;

No. 7: Model 290-S-T-Earmuff (gray), Safety Supply Co., Canada; it is used when helmets are not required;

No. 8: Model 290-S Safe-T-Earmuff (yellow), Safety Supply Co., Canada; It is used mainly in workshops and open-pits when mounted on helmet;

No. 9: Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.; It is used by the military, particularly the navy, and in workshops, very little used in mines;

No. 10: Model E-805 Straightaway, D. Clark, U.S.A.; it is used by the military, in workshops and in mines; and

No. 11: Sound Barrier EM 152, Willson, U.S.A.; it is used mainly by industry and in mines.

4. 1. Psychophysical Method

The ear muff attenuations had been measured as a transmission loss; the difference between the noise level outside the ear muff (measured 0. 1 m from the side of the head) and that inside the ear muff (26). These measurements were not in compliance with the American Standards Association's requirements (27) (28).

4. 1. 1. Equipment

A block diagram of the test equipment is shown in Fig. 12. The test signals were produced with a Brüel and Kjaer, random noise generator, type 1402. An acoustical mirror was used to obtain a constant sound level of the test signal. The high powered loudspeaker was placed 1 m from the subject, as shown in Fig. 12. Microphones were suspended at the subject's ear: one under the cup and one over the cup, 1. 3 m above the floor, and located in the room's centre.

The basic system for measuring sound pressure levels with a sound

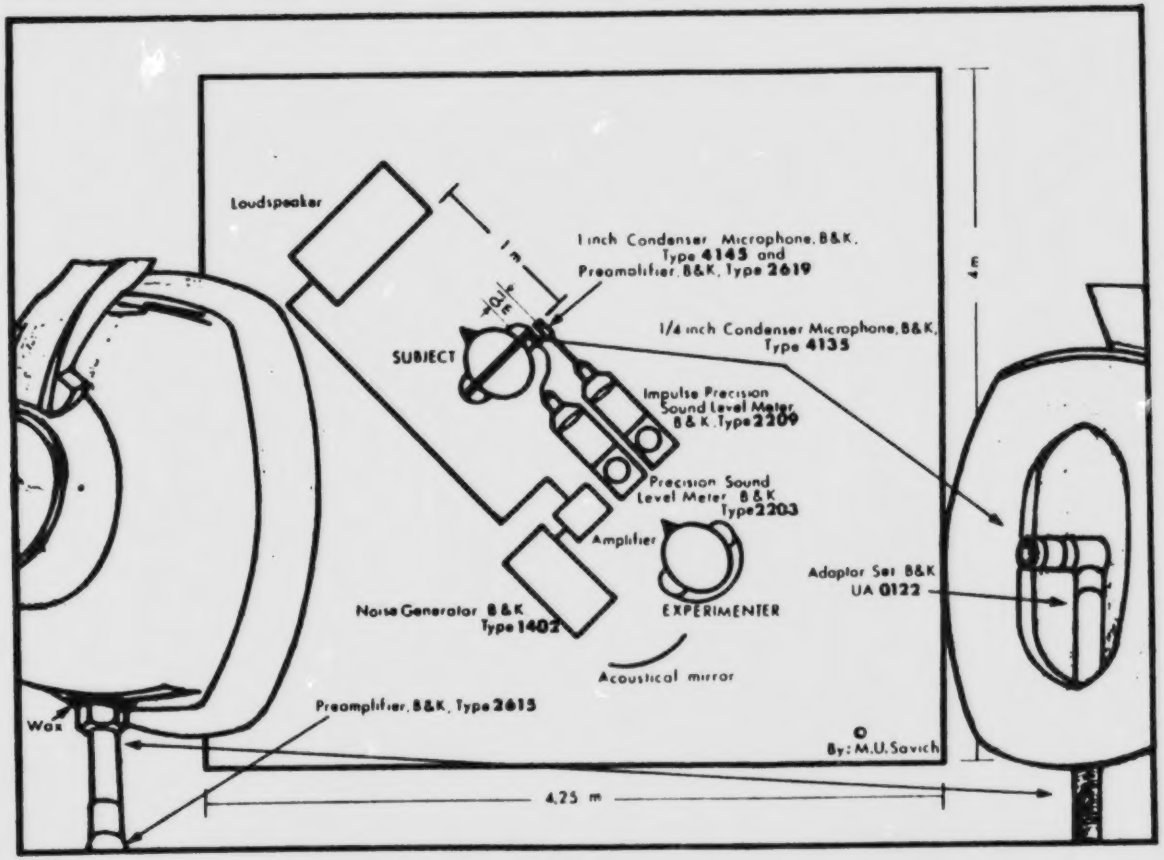
Loudspeaker
1 m
0.1 m
1 inch Condenser Microphone, B&K, Type 4145 and Preamplifier, B&K, Type 2619
1/4 inch Condenser Microphone, B&K, Type 4135
4 m
SUBJECT
Impulse Precision Sound Level Meter, B & K, Type 2209
Precision Sound Level Meter B & K Type 2203
Amplifier
Adaptor Set B&K UA 0122
Noise Generator B & K Type 1402
EXPERIMENTER
Acoustical mirror
Preamplifier, B&K, Type 2615
Wax
©
By: M.U. Savich
4.25 m

Fig. 12: Block diagram of experimental instruments for measuring the attenuation of ear muffs.

level meter consists of the following (29):

1. Transducer:
   a) The microphone over the cup was a 1 in. condenser microphone, type 4145, B and K.
   b) The microphone under the cup was a ¼ in. condenser microphone, type 4135, B and K.
2. Preamplifier:
   a) The preamplifier over the cup was a type 2619, B and K (IEC R 327 and ANSI S1.70 - 1966).
   b) The preamplifier under the cup was a type 2615, B and K (IEC R 327 and ANSI S1.70 - 1966).
3. Sound level meter (IEC R 123 and ANSI S1.4 - 1971):
   a) Impulse precision sound level meter, type 2209, B and K, which had the following: a frequency range of 2 Hz to 70 kHz; A, B, C and D weighting network, linear frequency response, and impulse measurement with max. RMS hold (IEC R 179). An octave filter, type 1613, B and K was connected to an impulse precision sound level meter.
   b) A precision sound level meter, type 2203, B and K, which had a frequency range 10 Hz to 25 kHz; A, B, and C weighting network, and linear frequency response. An octave filter, type 1613, B and K, was connected to a precision sound level meter.
4. The calibrator was a pistonphone, type 4220, B and K, and the sound level calibrator was a type 4230, B and K.

5. Headband (clamping) force apparatus are developed in the Elliot Lake Laboratory. The apparatus is described in Appendix E-2.

4. 1. 2. Subject Selection and Test Room

Two subjects for these tests were selected from the laboratory personnel. Subject 1 (age 35) with long hair, had a mezzocephalic head with a bizygomatic diameter of 13. 6 cm (significantly smaller than average), and subject 2 (age 54) short haired, had a brachycephalic head with a bizygomatic diameter of 16. 5 cm (significantly larger than average) (Fig. 13). In this case the human head replaced the dummy's.

The tests were conducted in a semi-reverberant room held at constant temperature, 4. 25 m long, 4 m wide and 2. 5 m high. The walls, ceiling and floor were constructed of wood and there was one window and one door in the room. The room was empty. Maximum ambient noise levels at the position of the subject (listener) were 35 dBA.

4. 1. 3. Test Procedure Using Human Heads

Fitting Procedure: The process of fitting an ear protector is one of the most important factors affecting the sound attenuation characteristics of the device. Prior to the tests, each of the subjects was taught the correct fitting procedures for the eleven models. The device was first positioned by the experimenter and then it was positioned by the subject for a final orientation for each test. The general aim of the test was to measure ear muff efficiency using only one measurement.

Attenuation Measurements: Measurements of variation in sound pressure levels for a constant test signal level were made on both the left and right

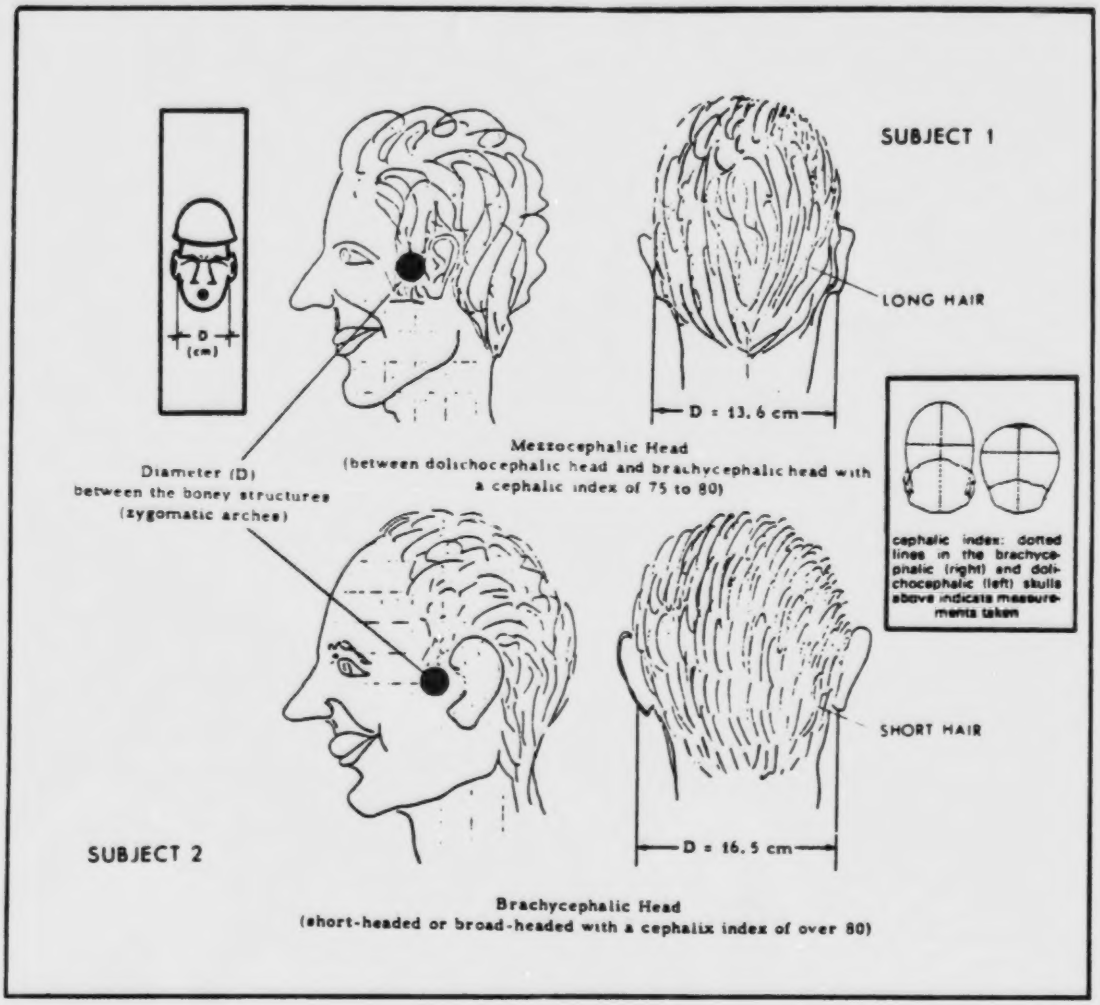
SUBJECT 1
D
(cm)
LONG HAIR
D = 13.6 cm
Mezzocephalic Head
(between dolichocephalic head and brachycephalic head with a cephalic index of 75 to 80)
Diameter (D) between the boney structures (zygomatic arches)
cephalic index: dotted lines in the brachycephalic (right) and dolichocephalic (left) skulls above indicate measurements taken
SHORT HAIR
SUBJECT 2
D = 16.5 cm
Brachycephalic Head
(short-headed or broad-headed with a cephalix index of over 80)

Fig. 13: Subjects for psychophysical tests.

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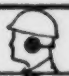
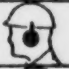
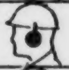
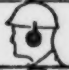
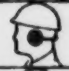
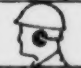
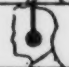
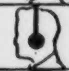
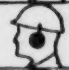
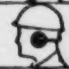
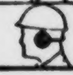
sides of the head. The ear muff attenuation was determined at the following frequencies: 125, 250, 1000, 2000, 4000 and 8000 Hz and at the dBA weighting network. Average noise levels of test signals, and the noise reduction ratings for eleven ear muffs were made (Table 11). There are 7 tests on each of two ears of each subject and 28 sets of measurements in all, except on one ear muff which had 4 extra tests.

TABLE 11

Test Signals and the Noise Reduction Rating* of Ear Muffs during the Psychophysical Method of Measurement

No.	Ear Muff	Band	No. of Tests		Noise Level (dB)							dBA	Reduction in dBA
					Frequency (Hz)								
					125	250	500	1000	2000	4000	8000		
1	Model 1675, Amer. Optical, U.S.A.		28	Mean Std. Dev.	76.35 1.79	82.68 1.00	94.91 1.04	102.89 1.49	107.84 1.03	103.20 0.67	94.82 1.22	111.09	34.2
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.		28	Mean Std. Dev.	74.25 0.78	79.32 0.48	91.41 1.05	98.89 1.15	103.86 1.05	100.36 1.25	91.95 1.28	107.44	31.1
3	Helmet Muffs -(HF), Bilsom, Sweden.		28	Mean Std. Dev.	76.91 1.28	83.09 1.10	94.55 1.00	102.41 0.60	107.71 0.75	103.77 0.90	94.80 1.00	111.08	36.8
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.		28	Mean Std. Dev.	74.60 0.55	79.48 0.40	91.89 0.84	99.09 0.79	104.91 0.99	100.21 0.99	92.80 1.53	108.06	37.5
5	Model NO NOISE, Hellberg, Sweden.		28	Mean Std. Dev.	74.14 2.98	79.66 2.87	91.79 2.48	99.09 3.08	104.43 3.10	100.64 3.09	90.65 5.83	107.79	39.9
6	Model Mark IV, MSA, U.S.A.		28	Mean Std. Dev.	76.89 0.35	82.91 0.89	94.32 0.97	102.00 0.81	107.86 0.86	103.36 0.72	95.39 1.00	111.07	38
7	Model 290-S Safe-T-Earmuff (gray), Safety Supply Co., Canada		32	Mean Std. Dev.	72.94 9.6	82.94 1.29	95.53 0.99	103.25 0.63	108.00 1.20	104.22 0.97	95.28 1.56	111.50	43.6
8	Model 290-S Safe-T-Earmuff (yellow), Safety Supply Co., Canada		28	Mean Std. Dev.	76.88 1.30	83.06 1.24	94.16 3.92	102.34 0.47	108.57 1.10	103.41 1.10	95.89 1.59	111.57	43.6
9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.		28	Mean Std. Dev.	73.70 2.92	80.25 0.66	92.05 0.48	99.23 0.66	104.00 1.12	100.61 0.63	91.68 2.06	107.59	35
10	Model E-805 Straightaway, D. Clark, U.S.A.		28	Mean Std. Dev.	77.05 0.87	82.07 1.14	95.07 0.86	102.64 1.41	107.59 0.79	103.61 0.96	95.14 1.05	111.01	36.3
11	Sound Barrier EM 152, Willson, U.S.A.		28	Mean Std. Dev.	73.68 0.98	79.29 0.60	91.09 0.67	98.70 0.66	103.39 0.83	100.14 0.69	91.16 1.40	107.03	36.4
Σ-7	All Ear Muffs (without No. 7 Ear Muff)		10 (280)	Mean Std. Dev.	75.45 1.24	81.18 1.07	93.12 1.22	100.73 1.11	106.02 1.14	101.93 1.10	93.43 1.41	109.37	37.1
Σ	All Ear Muffs		11 (312)	Mean Std. Dev.	75.21 1.47	81.34 1.08	93.34 1.20	100.96 1.08	106.20 1.13	102.14 1.09	93.60 1.40	109.37	37

* Appendix A-1, Computer Program

4. 1. 4. Effect of Glasses and Adaptors on Attenuation of Ear Muffs

During this test the listener's neck joint was in normal position. The raw data of attenuation tests of ear muffs are summarized in a graph (with frequency in hertz) (Appendices B-1 to B-11) and in a table (dBA - network) (Appendix B-12). Total noise was estimated from the octave-band noise levels. Approximate agreement with the total noise measured indicates a reasonably constant condition during the period of measurement.

Measurements of ear muff attenuations were made in the current series of tests with: (a) ear muffs, (b) ear muffs and glasses, and (c) ear muffs, glasses and adapter. Muff/eyeglass adapters were specially designed for people wearing glasses in conjunction with hearing protectors. It should be pointed out that at 125 Hz the attenuation is approximately 15 dB higher than normal. This was caused by distortion which is a change in transmitted sound that alters the character of the energy - frequency distribution within the signal so that the sound being received is not a faithful replica of the source sound.

The attenuation was observed in a semi-reverberant field with sound directed at the face. Differences in attenuation of 10 dB or more were observed over all frequencies (Appendices B-1 to B-11). The resulting differences in attenuation values over eleven ear muffs are found among subjects and between measurements on the same subject (Appendices B-7a and B-7b). On the same subject, left hemisphere versus right henesphere attenuation differed. Probably for convenience and simplicity, the A-weighted sound level has become the most common single number rating for hearing damage risk. OSHA legislation regarding noise pollution bases noise criteria on A-weighted sound levels in dBA (Table 1). Data reduction results were tabulated in dBA weighting network (Appendix B-12) so that better understanding and clearer presentation were possible. Data analyses in reduced form for estimation of the degree of environmental hazard were presented in the situation of the neck joint in normal position (Table 12). From the summary results in Table 12 the following can be concluded:

1. Attenuation for subject 2 with large head and short hair is higher than attenuation for subject 1 with long hair, except in four measurements.
2. Ear muffs No. 3, No. 5, and No. 8 have almost equal attenuations for both subjects.
3. The largest attenuation difference for both subjects occurred with the No. 6 ear muff. This is because of the long hair worn by subject 1. The same thing occurred with ear muffs No. 2, 7, 9 and 10.
4. With the use of glasses and their adapters, attenuation decreases. The adapters, are not effective barriers.
5. Efficiency of ear muffs is not equal:

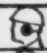
Ear Muff No.	1	2	3	4	5	6	7	8	9	10	11
Noise Reduction* (dBA)	34.2	31.1	36.8	37.5	39.9	38	43.6	43.6	35	36.3	36.4
Attenuation** (dBA)	27.27	29.66	30	29.95	31.54	27.04	29.88	34.77	31.64	32.06	27.29
Difference (dBA)	6.93	1.44	6.8	7.55	8.36	10.96	13.72	8.83	3.36	4.24	9.11
Order of Performance✿	5	1	4	6	7	10	11	8	2	3	9

NOTE: * From Table 11
** From Table 12
✿ 1 = best; 11 = worst

Only No. 2 ear muff came close to the theoretical attenuation value. The largest attenuation was displayed by ear muff No. 8.

TABLE 12

Attenuation Data Analysis in Reduced Form for the Neck Joint in Normal Position

No.	Ear Muff	Band	Subject	(cm)	Clamping Force (g wt)	Attenuation (dBA)																	
						Muff					Muff and Glasses					Muff, Glasses and Adapter						Summary	
						Left Ear (L)	Right Ear (R)	$\frac{L+R}{2}$	(L + R) / 2		Left Ear (L)	Right Ear (R)	$\frac{L+R}{2}$	(L + R) / 2		Left Ear (L)	Right Ear (R)	$\frac{L+R}{2}$	(L + R) / 2		$\frac{L+R}{2}$	(L + R) / 2	
									Difference	Average				Difference	Average				Difference	Average		Difference	Average
1	Model 1675, Amer. Optical, U.S.A.		1 2	13.6 16.5	980 780	28 34.25	28.5 28.25	28.25 31.25	+ 3	29.75	24.25 33.25	28 26.75	26.12 30	+ 3.88	28.06	18.5 32.25	26 19.25	22.25 25.75	+ 3.5	24	25.56 29	+ 3.44	27.27
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.	①	1 2	13.6 16.5	1005 1355	29.75 37	31.5 31.5	30.62 34.25	+ 3.63	32.43	27 35	25.25 34	26.12 34.5	+ 8.38	30.31	24.5 29.5	21 30	22.75 29.75	+ 7	26.25	26.5 32.83	+ 6.33	29.66
3	Helmet Muffs - (HT), Bilsom, Sweden.	②	1 2	13.6 16.5	730 930	26 30.5	31 28.25	28.5 29.37	+ 0.87	28.93	33 33	28 30	30.5 31.5	+ 1	31	34 32	24.25 31	29.12 31.5	+ 2.38	30.31	29.21 30.79	+ 1.58	30
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	②	1 2	13.6 16.5	980 1230	31.5 33.75	28.75 32.75	30.12 33.25	+ 3.13	31.68	30 31.5	25.75 38.25	27.87 34.87	+ 7	31.37	33 28.75	24 29.5	28.5 29.12	+ 0.62	28.81	28.83 31.08	+ 2.25	29.95
5	Model NO NOISE, Hellberg, Sweden.		1 2	13.6 16.5	1580 2580	25 32.5	30.5 33.75	27.75 33.12	+ 5.37	30.43	36 32.5	30.5 33.75	33.25 33.12	- 0.13	33.18	32.25 29.75	30.75 31.75	31.5 30.25	- 1.25	30.87	30.83 32.12	+ 1.29	31.47
6	Model Mark IV, MSA, U.S.A.		1 2	13.6 16.5	1180 1580	15.5 34.25	21.25 36.5	18.37 35.37	+ 17	26.87	14.25 33.25	20.5 33.5	17.37 33.37	+ 16	25.37	25.5 32.25	20.5 37.25	23 34.75	+ 11.75	28.87	19.58 34.5	+ 14.92	27.04
7	Model 290-S Safe-T-Earmuff (grey), Safety Supply Co., Canada		1 2	13.6 16.5	1230 1480	30.7 32.6	23.5 37.3	27.1 34.95	+ 7.85	31.02	30.4 34.1	17.4 34.4	23.9 34.25	+ 10.35	29.07	30.5 30.3	24.8 32.7	27.65 31.5	+ 3.85	29.57	26.21 31.56	+ 5.35	28.88
8	Model 290-S Safe-T-Earmuff (yellow), Safety Supply Co., Canada		1 2	13.6 16.5	1130 1330	34 38.5	42.25 35	38.12 36.75	- 1.37	37.43	29.25 34.75	36 32.75	32.62 33.75	+ 1.13	33.18	31.25 32.5	37.25 33.75	34.25 33.12	- 1.13	33.68	35 34.54	- 0.46	34.77
9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.	②	1 2	13.6 16.5	730 1005	31.25 35.5	27 33	29.12 34.25	+ 5.13	31.68	29.25 37.75	28.25 33.75	28.75 35.75	+ 7	32.25	28.25 35.25	27 33.5	27.62 34.37	+ 6.75	30.99	28.5 34.79	+ 6.29	31.64
10	Model E-805 Straightaway, D. Clark, U.S.A.		1 2	13.6 16.5	1330 1930	30.25 34.5	32.5 38.75	31.37 36.62	+ 5.25	33.99	29 33.75	31.75 34.5	30.37 34.12	+ 3.75	32.24	28.5 33	27 35.25	27.75 34.12	+ 6.37	30.93	29.83 34.29	+ 4.46	32.06
11	Sound Barrier ED 157, Willson, U.S.A.		1 2	13.6 16.5	980 1280	23.5 28.25	27.25 31.5	25.37 29.87	+ 4.5	27.62	28 26.25	27 32	27.5 29.12	+ 1.62	28.31	24.5 27.75	25 26.5	24.75 27.12	+ 2.37	25.93	25.87 28.7	+ 2.83	27.29
I - II	Mean Std. Dev.	-	1	13.6	1077.7 377.9	27.77 5.13	29.45 5.44	28.61 4.72	+ (4.76 ± 2.23 Std. Error		28.22 5.44	27.13 5.08	27.67 4.44	+ (5.09 ± 2.06) Std. Error		27.98 4.36	26.12 4.60	27.05 3.79	+ (3.98 ± 0.94) Std. Error		27.81 3.06	+ (4.57 ± 1.98) Std. Error	
	Mean Std. Dev.	-	2	16.5	1407.3 568.3	33.78 2.84	32.96 2.97	33.37 2.32			33.37 2.35	32.15 2.52	32.76 2.09			31.16 2.21	30.95 4.06	31.03 2.97			32.38 2.22		
Σ	Mean Std. Dev.	-	1 & 2	-	1242.5 465.4	29.64 5.25	31.30 4.78	30.99 4.37		30.98 2.88	30.79 4.92	29.64 4.68	30.21 4.27		30.21 2.45	29.57 3.75	28.64 5.19	29.09 3.05		29.06 2.77	30.09 3.87		30.1 2.36

NOTE. ① Tested while mounted on helmet; B & 10A Safety Cap, CSA Standard Z 94.1
② Tested while mounted on helmet; Class C, CSA Standard Z 94.1

4.1.5. Effect of Movement of Joint of the Neck Flexion and Neck Rotation on Attenuation of Ear Muffs.

This test was similar to the previous one. The objective of this test was to see the stability of ear muffs on heads in motion, and to measure air leaks when wearing glasses. Ear muff attenuation measurements were performed in four positions (using one measurement) (Fig. 14):

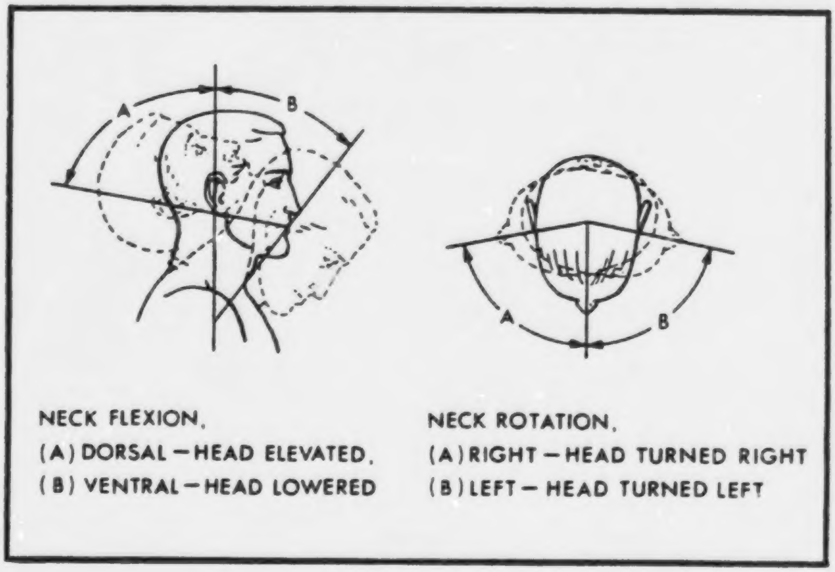

A
B
A
B
NECK FLEXION,
(A) DORSAL – HEAD ELEVATED,
(B) VENTRAL – HEAD LOWERED
NECK ROTATION,
(A) RIGHT – HEAD TURNED RIGHT
(B) LEFT – HEAD TURNED LEFT

Fig. 14: Neck flexion and neck rotation.

1. Neck flexion:
   a) Dorsal - head elevated,
   b) Ventral - head lowered.
2. Neck rotation:
   a) Right - head turned right,
   b) Left - head turned left.

Due to a lack of time, the left hemisphere was tested with glasses and the right hemisphere was tested without them. Raw data results are computed and given in a graph (with frequency in hertz) (Appendices B-13 to B-22), and in a table (dBA-network) (Appendices B-23 and B-24). Tests in Appendices B-13 to B-22 are similar to tests in Appendices B-1 to B-11, because these events were often repeated.

The analyses of environmental data were presented in reduced form, for some intended purpose, such as estimation of the degree of environmental hazards in a situation where the neck joint is flexed and the neck rotated (Table 13). From the results in Table 12 the following can be concluded:

1. There are no great differences in attenuation when the neck moves;
2. The test performed on subject 1 (D = 13.6 cm) showed that the amount of hair trapped between the ear muff cushion and the head had a significant effect on ear muff attenuation.
3. The largest difference in attenuation between two subjects is once again with the No. 6 ear muff (left side 16 dBA, and right side 18.06 dBA).
4. The greatest attenuation occurred with the No. 10 ear muff on both subjects (34.21 dBA).
5. On the average, with both subjects, glasses decreased attenuation by 1.42 dBA.
6. The efficiency of ear muffs is not equal:

Ear Muff No.	1	2	3	4	5	6	7	8	9	10	11
Noise Reduction* (dBA)	34.2	31.1	36.8	37.5	39.9	38	43.6	43.6	35	36.3	34.4
Attenuation** (dBA)	29.98	28.99	29.79	30.72	27.88	26.92	-	31.84	29.25	34.21	29.09
Difference (dBA)	4.22	2.11	7.01	6.78	12.02	11.08	-	11.76	5.75	2.09	5.31
Order of Performance ✿	3	2	7	6	10	8	-	9	5	1	4

NOTE: * From Table 11
** From Table 13
✿ 1 = best; 10 = worst

TABLE 13

Attenuation Data Analysis in Reduced Form Where the Neck Joint is Flexed and the Neck Rotated

No.	Ear Muff	Band	Subject	B (cm)	Clamping Force (g wt)	Attenuation (dBA) Left Hemisphere with Glasses							Right Hemisphere without Glasses							Left and Right Hemispheres	
						Head elevated	Head lowered	Head turned right	Head turned left	Average	Difference	Total Average	Head elevated	Head lowered	Head turned right	Head turned left	Average	Difference	Total Average	Total Difference	Total Average
1	Model 1675, Amer. Optical, U.S.A.		1 2	13.6 16.5	500 700	26.5 32.25	27 31.25	27.25 28.75	24.25 34.75	26.25 31.75	+ 5.5	29	30.5 31.75	29.25 32	32.5 35.25	27.25 29.25	29.87 32.06	+ 2.19	30.97	- 1.97	29.98
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.	①	1 2	13.6 16.5	1005 1355	24.75 32.65	23.25 31.65	21 25	26.5 35.5	23.87 31.15	+ 7.28	27.51	27 31.5	32.25 33	29.25 33.5	25.25 32	28.44 32.5	+ 4.06	30.47	- 2.96	28.99
3	Helmet Muffs -(HT), Bilsom, Sweden.	②	1 2	13.6 16.5	730 910	22 32.25	25.75 32.5	21.5 28.5	25 34	23.56 31.81	+ 8.25	27.69	28.75 30	32.25 34.75	29.75 36	30.25 33.5	30.25 33.56	+ 3.31	31.9	- 4.21	29.79
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	②	1 2	13.6 16.5	980 1210	20.25 34.5	32.75 38	29 30.5	35.5 36	29.37 34.75	+ 5.38	32.06	23.5 32.5	27.25 32	28.75 34.25	25.25 31.5	26.19 32.56	+ 6.37	29.38	+ 2.68	30.72
5	Model NO NOISE, Hellberg, Sweden.		1 2	13.6 16.5	1900 2500	22.75 28	26 28	27.25 27	30.5 30.25	26.62 28.31	+ 1.69	27.47	30.25 28.75	29.75 26	29.25 31.25	22.75 26.25	28 28.06	+ 0.06	28.03	- 0.56	27.75
6	Model Mark IV, MSA, U.S.A.		1 2	13.6 16.5	1100 1900	19.75 32	14.25 34.5	13.5 29.25	19.5 35.25	16.75 32.75	+ 16	24.75	26 27	16.5 30.75	22.5 35.25	15.25 27.5	20.06 30.12	+ 10.06	25.09	- 0.34	24.92
7	Model 259-S Safe-T-Earmuff (gray), Safety Supply Co., Canada		1 2	13.6 16.5	1230 1400	- -	- -	- -	- -	- -	-	-	- -	- -	- -	- -	- -	-	-	-	-
8	Model 216-S Safe-T-Earmuff (yellow), Safety Supply Co., Canada		1 2	13.6 16.5	1130 1330	28.75 36.5	28.25 35.75	27.75 38.75	30 34.75	28.69 36.44	+ 7.75	32.56	26.25 39.5	21.75 38.75	25 36.25	19.75 41.75	23.19 39.06	+ 15.87	31.13	+ 1.43	31.84
9	Model E-755 Straightaway Helmet Muffs, D. Clark, U.S.A.	②	1 2	13.6 16.5	730 1005	20.75 32.75	27.5 25.5	23.25 29.25	30.75 35	25.56 30.62	+ 5.06	28.09	27.75 26.5	25.25 33.25	27 36.5	28 33	26 30.8	+ 4.8	28.41	- 0.32	28.25
10	Model E-805 Straightaway, D. Clark, U.S.A.		1 2	13.6 16.5	1330 1930	32.25 33.75	33.5 33	35 33.5	33 37.5	33.44 34.31	+ 0.87	33.87	34.7 35.25	33.8 34.5	32.65 36.25	36.7 32.75	34.41 34.69	+ 0.28	34.55	- 0.68	34.21
11	Sound Barrier EM 152, Willson, U.S.A.		1 2	13.6 16.5	980 1200	26.25 28.75	23.75 30.5	28 37	28.25 34.5	26.56 32.19	+ 5.63	29.37	28.5 32.5	27.5 32.75	30.75 36.25	26 33.5	28.19 33.25	+ 5.06	30.72	- 1.35	30.05
[illegible]	Mean Std. Dev.	-	1	13.6	1077.7 377.9	25.6 3.64	26.2 5.30	24.55 5.96	28.32 4.66	26.17 4.59	+ (5.96 ± 2.15) Std. Error	-	28.32 3.06	27.55 5.29	28.72 3.15	25.64 5.8	27.56 3.92	+ (6.01 ± 2.24) Std. Error	-	-	-
[illegible]	Mean Std. Dev.	-	2	16.5	1407.3 502.3	32.30 2.50	31.64 2.35	29.75 3.09	34.74 1.85	32.11 2.21			32.32 4.25	33.07 3.40	36.17 3.29	32.9 4.61	33.57 3.16				
Σ	Mean Std. Dev.	-	1 & 2	-	1242.5 465.4	28.97 4.6	28.92 4.91	27.15 5.58	31.53 4.77	29.14 4.65	-	29.14 2.86	30.32 4.15	30.71 5.41	31.95 4.18	29.27 6.31	30.56 4.64	-	30.56 1.81	-	29.87 2.08

NOTE ① Tested while mounted on helmet, B = 18A Safety Cap, CSA Standard Z 94.1

② Tested while mounted on helmet, Class C, CSA Standard Z 94.1

Ear muffs No. 2 and No. 10 had the best efficiency with reference to the theoretical attenuation. Also ear muff No. 10 demonstrated the best attenuation of all ear muffs.

4.1.6. Cushion Seals and Clamping Force

Manufacturers' specified attenuations were attained on ear muffs No. 2 and No. 10 and only when worn on large head, subject 2. This was caused by an increase in clamping force and short hair. The hair length had the largest effect on ear muff attenuation even though this ear muff has cushion seals that retain softness. With the use of glasses and adapters attenuation decreased substantially on small as well as large heads. Eye-glass adapters do not have the characteristics attributed to them in the literature (30). The cause is simple: new materials for cushion seals perform the function of adapters (Fig. 15). The No. 3 ear muff has foam filled cushions with covering material of soft, supple plastic film (Fig. 15 (2)). As can be seen from tests in Table 12, the No. 6 ear muff increases

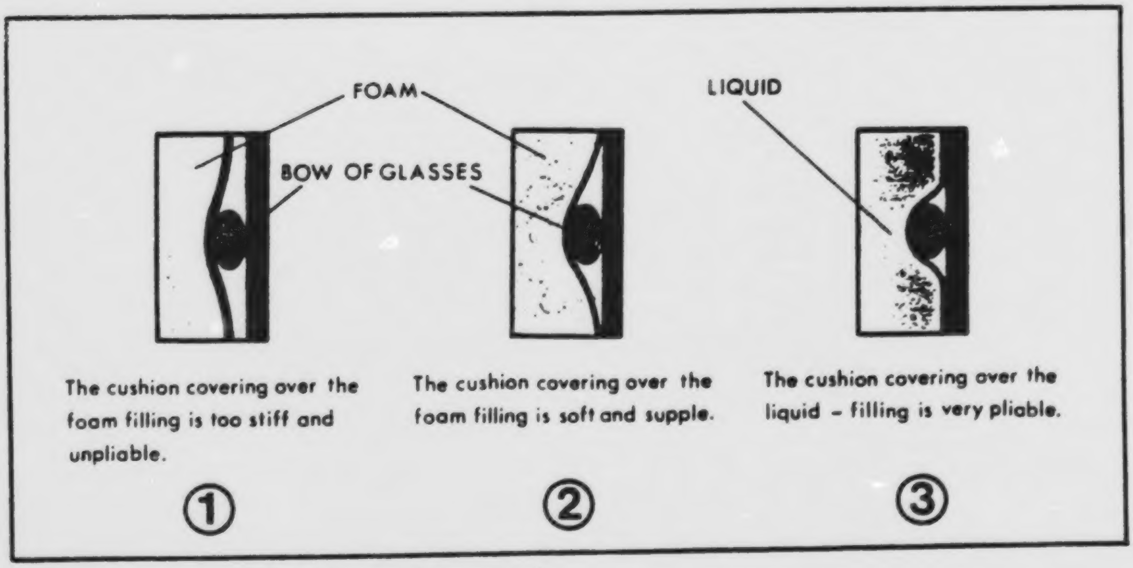

FOAM
LIQUID
BOW OF GLASSES
The cushion covering over the foam filling is too stiff and unpliable.
The cushion covering over the foam filling is soft and supple.
The cushion covering over the liquid - filling is very pliable.
①
②
③

Fig. 15: Material for cushion seals.

attenuation with the use of eye-glass adapters because the foam filled cushions with covering material are too stiff and unpliable (Fig. 15 (1)). Only ear muff No. 7 was tested twice to verify the efficiency of fluid-filled cushions (Appendices B-7/a and B-7/b). Cushion seal efficiency was very good (Fig. 15 (3)). It should be mentioned that liquid-filled cushions can be designed so that they fail to give optimum attenuation (8).

Attenuation mainly depends upon two factors: clamping force and cushion seals. From Tables 12 and 13 it is evident that an increase in clamping force results in an increased attenuation.

For the measurement of clamping (head band) force two pieces of apparatus were constructed in the Elliot Lake Laboratory.
One for the measurement of clamping forces of ear muffs with head band, (Appendix E-2), and another for the measurement of clamping forces of ear muffs mounted on helmets (Appendix E-3). The second apparatus measures the assymmetry of clamping forces with a helmet.

4. 2. Physical Method

Ear muff attenuation was measured as the difference between the outputs of the microphone uncovered and the cup covered microphone. For this test the apparatus to determine the efficiency of cup cushions under different clamping forces was made in the Elliot Lake Laboratory (Fig. 16).

4. 2. 1. Instrumentation.

The sound field of a pure tone at 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz and 8000 Hz, was generated by a Hewlett-Packard test oscillator, model 650A. A loud-speaker was placed 1 m from the centre of the apparatus taken in

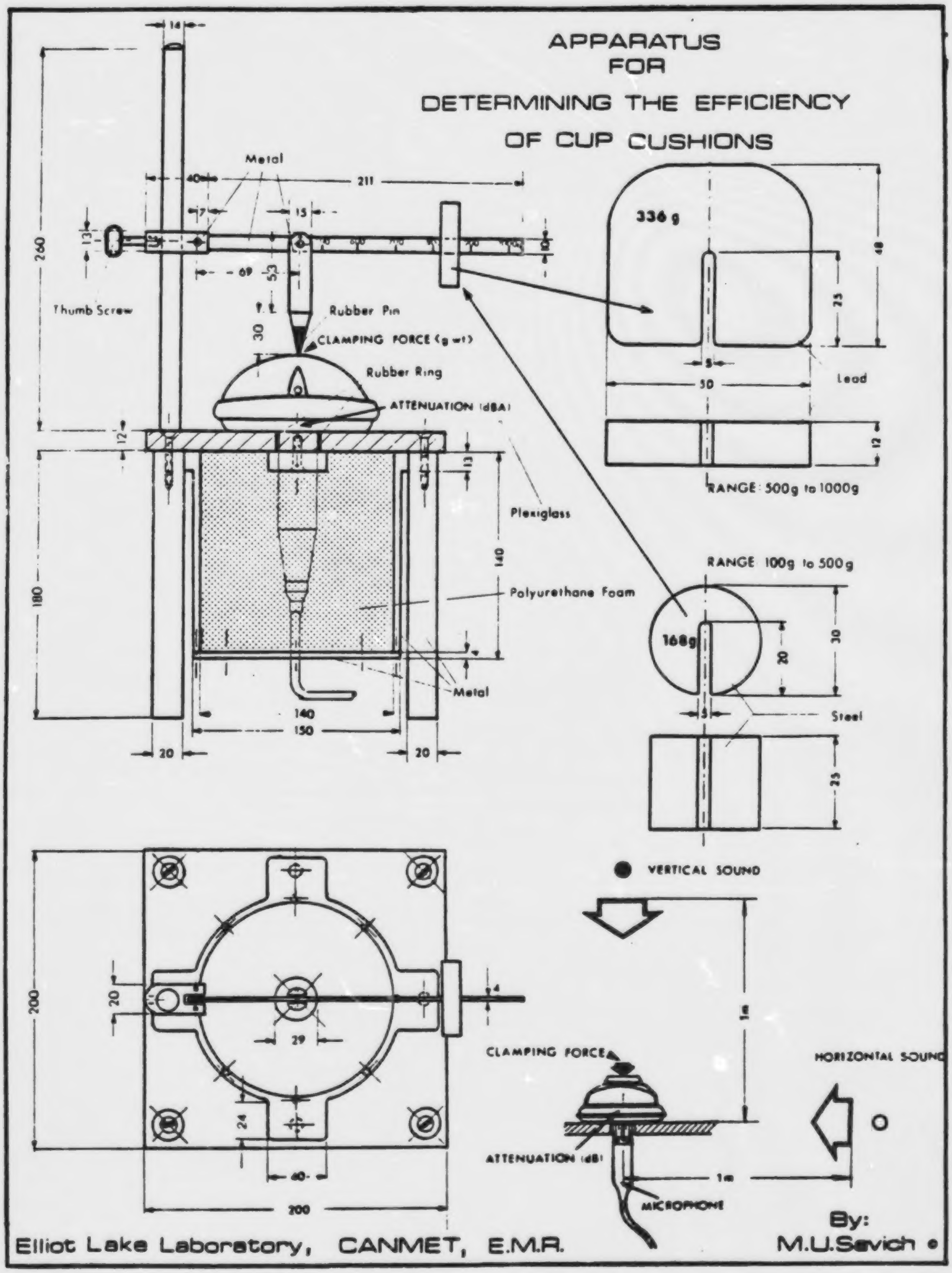

APPARATUS FOR DETERMINING THE EFFICIENCY OF CUP CUSHIONS
Metal
Thumb Screw
Rubber Pin
CLAMPING FORCE (g wt)
Rubber Ring
ATTENUATION (dBA)
Plexiglass
Polyurethane Foam
Metal
336 g
Lead
RANGE: 500g to 1000g
RANGE 100g to 500g
168g
Steel
VERTICAL SOUND
CLAMPING FORCE
HORIZONTAL SOUND
ATTENUATION (dB)
MICROPHONE
1m
Elliot Lake Laboratory, CANMET, E.M.R.
By: M.U.Savich

Fig. 16: Apparatus for determining the efficiency of cup cushions.

(Cont. overleaf)

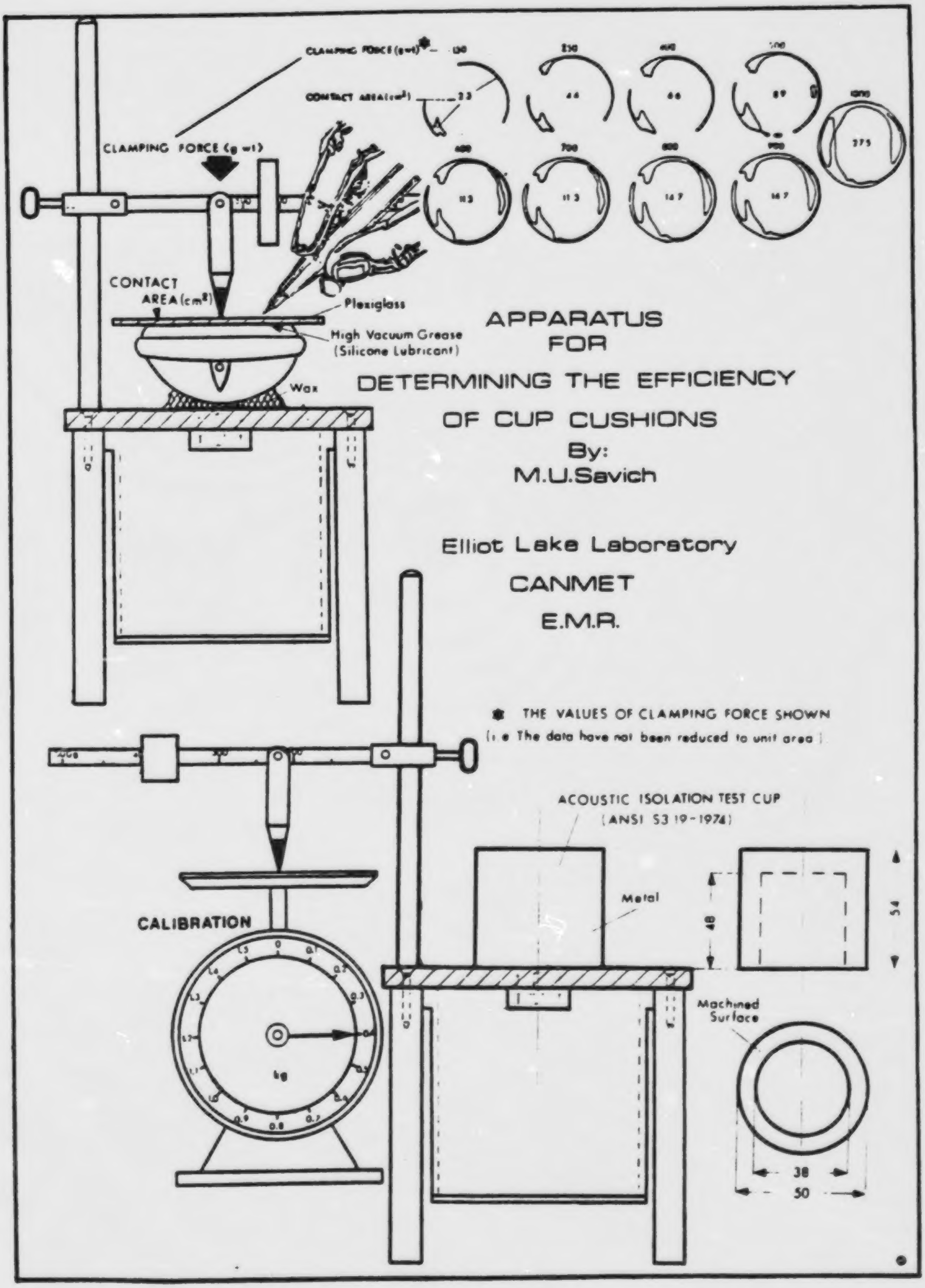

CLAMPING FORCE (g wt)* — 130
CONTACT AREA (cm²) — 22
230
44
400
66
500
89
1000
275
600
113
700
113
800
147
900
147
CLAMPING FORCE (g wt)
CONTACT AREA (cm²)
Plexiglass
High Vacuum Grease (Silicone Lubricant)
Wax
APPARATUS FOR DETERMINING THE EFFICIENCY OF CUP CUSHIONS
By: M.U.Savich
Elliot Lake Laboratory
CANMET
E.M.R.
* THE VALUES OF CLAMPING FORCE SHOWN (i.e. The data have not been reduced to unit area)
ACOUSTIC ISOLATION TEST CUP (ANSI S3.19-1974)
Metal
48
54
Machined Surface
38
50
CALIBRATION
kg

Fig. 16 Cont.: Apparatus for determining the efficiency of cup cushions.

horizontal and vertical directions. A B and K microphone, type 4145, and a B and K preamplifier, type 2615 were placed in the apparatus to determine the efficiency of cup cushions. The measurements were observed by Brüel and Kjaer impulse precision sound level meter, type 2209, in the dBA weighting network. The reading made is taken to the sound level. The measuring system used was calibrated by the pistonphone, a Brüel and Kjaer type 4220, to measure band pressure level with reference to 20 μ Pa(Pa=N/m^2).

4. 2. 2. Apparatus

The apparatus for determining the efficiency of cup cushions was constructed in accordance with the dimensions shown in Fig. 16. Both cups of an ear muff could have been tested on this apparatus separately, however, only one cup was tested because of lack of time.

Acoustical isolation of the apparatus was less than 60 dB in any test frequency band in the range of interest. A sample test cup is shown in Fig. 16 (ANSI S3. 19 - 1974).

4. 2. 3. Test Procedure

The ear cup was spread and placed on the plane plexiglass surface. The steelyard's rubber pin was pressed against the ear cup and a clamping force was selected. Loss of attenuation by an ear cup under a constant clamping force and different pure tone test signal level was examined. These data demonstrate that the range of loss is approximately the same when ambient levels range from 80 dBA to 110 dBA. Output test signal data are presented in Table 14.

TABLE 14

Output Test Signal

No.	Ear Muff	Horizontal Sound in dBA						Vertical Sound in dBA					
		Pure Tone Test Signal at Selected Frequency (Hz)						Pure Tone Test Signal at Selected Frequency (Hz)					
		500	1000	2000	3000	4000	8000	500	1000	2000	3000	4000	8000
1	Model 1675, Amer. Optical, U.S.A.	90	100	105	100	100	80	90	100	110	95	100	80
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.	90	100	105	100	95	80	95	105	110	100	100	80
3	Helmet Muffs -(HF), Bilsom, Sweden.	95	100	105	100	100	80	95	100	110	100	95	80
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	90	100	105	100	100	80	95	100	110	95	100	75
5	Model NO NOISE, Hellberg, Sweden.	95	100	105	100	100	80	100	105	110	95	100	80
6	Model Mark IV, MSA, U.S.A.	95	100	100	100	90	80	90	100	110	95	100	80
7	Model 290-S Safe-T-Earmuff (gray), Safety Supply Co., Canada.	90	100	105	100	100	80	95	100	105	95	95	75
8	Model 290-S Safe-T-Earmuff (yellow) Safety Supply Co., Canada.	95	100	105	100	100	75	95	105	110	95	100	80
9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.	100	100	95	100	100	80	95	100	110	90	100	80
10	Model E-805 Straightaway, D. Clark, U.S.A.	95	100	105	100	100	80	95	105	110	100	100	75
11	Sound Barrier EM 152, Willson, U.S.A.	95	100	105	105	100	80	100	105	110	100	100	75
$\bar{x}$	Mean	93.64	100	103.64	100.45	98.64	79.54	95.45	102.27	109.54	96.36	99.09	78.18
	Std. Dev.	3.23	0	3.23	1.51	3.23	1.51	2.70	2.61	1.51	3.23	2.02	2.52

4. 2. 4. Measurement

The sound pressure levels at the microphone were measured for the acoustic test field without an ear cup. Afterwards the hearing protector was placed over the microphone and the sound pressure levels were measured again. Readings are taken at the preferred centre frequency, and at the preferred clamping (head band) force. The measurements should be taken for right and left ear cups. When the measured difference between ear cups is 5 dB or greater, the attenuation of each ear cup should be reported (ANSI S3. 19 - 1974).

When the No. 5 ear muff was tested, comparison of attenuation was made with and without a chamois cloth between ear cup and plexiglass (Fig. 17). No major differences between covered (with a chamois cloth) and uncovered plexiglass occurred. Only at 4 kHz (horizontal sound) are differences without a tolerance limit. Because of this, all tests were conducted without a chamois cloth.

4. 2. 5. Ear Muff Attenuation

The algebraic difference in sound pressure levels, in dBA weighting network, at each test frequency signal, with and without the ear cup in place on the plexiglass, is considered to be the attenuation of the device. The attenuation data and efficiency of cup cushions from eleven ear muffs were presented in graphic form (Appendix C).

For a discussion of results, the clamping force at 450 (g wt) for one cup was used as a basic level (ANSI S3. 19 - 1974). From the formula $F = b\,W/a$, used in the force measurement system, the clamping (head band)

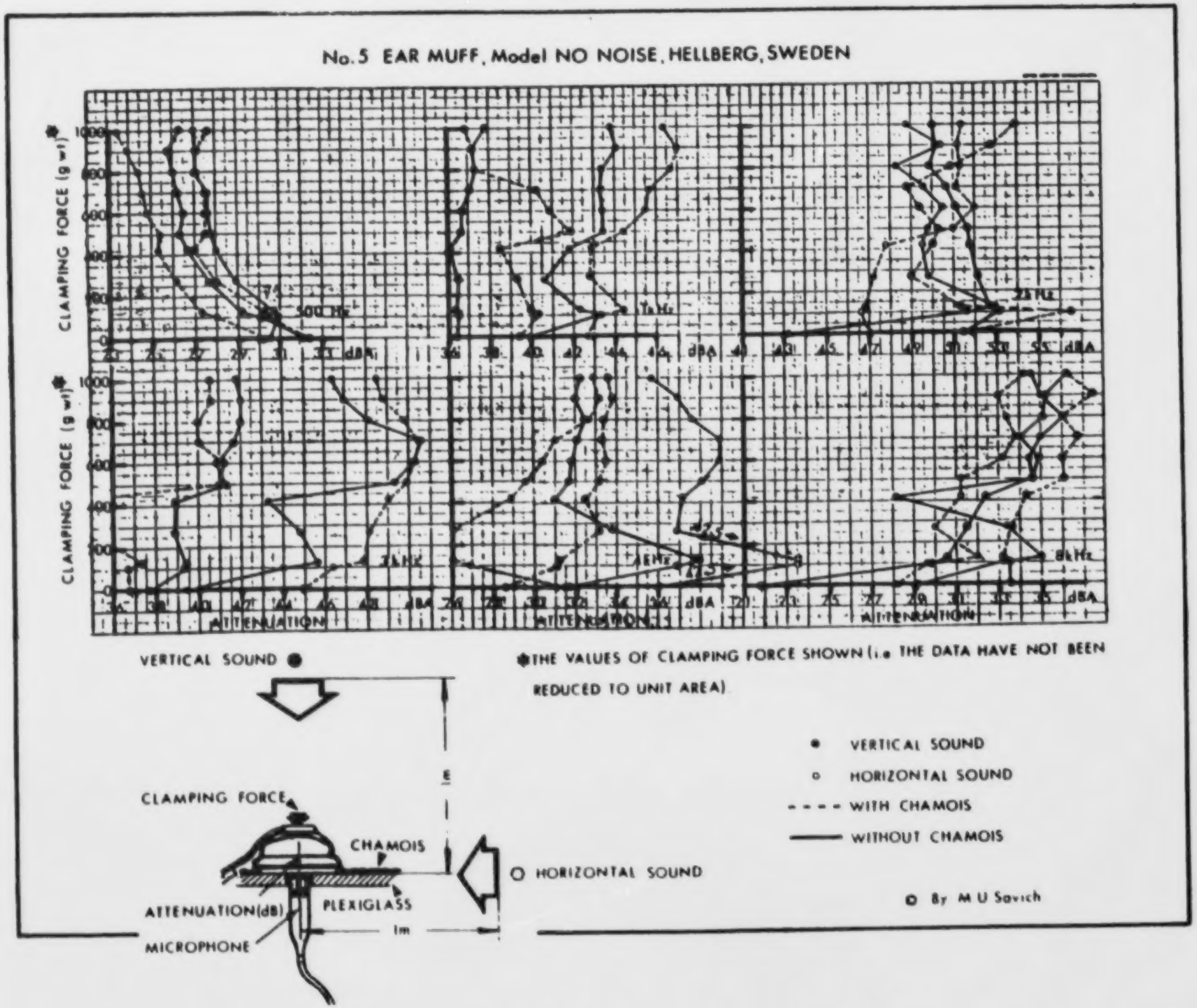


Fig. 17: Ear cup attenuations with and without a chamois cloth.

force will be 900 (g wt) if b = a (Appendix E-1). Also, attenuation characteristics measured in accordance with ANSI Z 24.22 - 1957 are included so as to be compared with the efficiency of cup cushions. All ear muffs should be divided into three main groups:

Group	Ear Muff	Force (g wt)	Attenuation Behaviour
1	No. 4, No. 5, No. 8, No. 9, and No. 10	150 to 350	Steady at all frequencies and clamping forces
2	No. 1, No. 3, and No. 6	350 to 550	Steady at some frequencies and clamping forces
3	No. 2, No. 7, and No. 11	>550	Variable at all frequencies and clamping forces

In general, the attenuation values of ear cups are dependent upon two factors:

1. Clamping (head band) force (g wt), and
2. Design of the ear cup cushion.

Both factors were taken into consideration in this test. It is evident from the graphs (Appendix C) that attenuation is a function of amount of air leakage. An air leak causes different losses of attenuation at various frequency test signals as well as different losses among the various ear muffs.

A greater attenuation is obtained when an ear cup is exposed to horizontal sound, than when it is exposed to vertical sound (Table 15). According to acoustical laws, the opposite should be expected. E. A. G. Shaw came to the same conclusion and this phenomenon is yet to be explained (31).

From graphs in Appendix C, one can see developing a rudimentary theory to guide us in the design of ear muffs. Physical measurements of

TABLE 15

Attenuation of Ear Muffs with Horizontal and Vertical Test Signals

	No.	Ear Muff	Horizontal Sound - Clamping Force 450 (g wt)						Vertical Sound - Clamping Force 450 (g wt)						
			Attenuation (dBA) of Pure Tone Test Signal at Selected Frequency (Hz)						Attenuation (dBA) of Pure Tone Test Signal at Selected Frequency (Hz)						
			500	1000	2000	3000	4000	8000	500	1000	2000	3000	4000	8000	
	1	Model 1675, Amer. Optical, U.S.A.	27	34	50	46	48	35	28.5	31.5	45	37.5	42	35.5	
	2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.	8	27	28	31	23	27	15	27.5	22	28	27	18.5	
	3	Helmet Muffs -(HF), Bilsom, Sweden.	25	36	46	37	43	34	28.5	33	44	40	41.5	31	
Same ear cup	4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	21	40	45	49	35	24	25.5	39	55.5	39.5	29	32	Same ear cup
	5	Model NO NOISE, Hellberg, Sweden.	28	43	50	46	37	29	26.5	36.5	52	40	31	33	
	6	Model Mark IV, MSA, U.S.A.	21	31	41	46	32	37	29	37	49.5	40	37.5	29	
Similar ear cup	7	Model 290-S Safe-T-Earmuff (gray), Safety Supply Co., Canada.	26	45	50	39	36	34	31	41	56	28.5	40	28	Similar ear cup
	8	Model 290-S Safe-T-Earmuff (yellow) Safety Supply Co., Canada.	33	42	47	46	39	25	34	45	43	39	45.5	31.5	
Same ear cup	9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.	35	45	32	35	45	33	35	43.5	42	23	36	29.5	Same ear cup
	10	Model E-805 Straightaway, D. Clark, U.S.A.	33	45	43	47	45	35	37.5	46.5	44	32.5	39.5	33	
	11	Sound Barrier EM 152, Willson, U.S.A.	29	37	51	46	27	30	38.5	42	46.5	36.5	26	21	
	I	Mean	26	38.64	43.91	42.54	37.27	31.18	29.91	38.41	45.41	34.95	35.91	29.27	
		Std. Dev.	7.54	6.15	7.62	5.96	7.84	4.42	6.58	5.97	9.19	6.01	6.65	5.18	

attenuation can provide valuable information.

This test explained the following:

1. Ear muffs with a small cushion area start serving their purpose more quickly because the force per square centimeter is larger;
2. A clamping force larger than 900 (g wt), in the first and second groups, does not cause an increase in attenuation;
3. Attenuation characteristics (ANSI Z24.22 - 1957) of ear muffs show a coincidence with physical tests. They cannot be completely compared because their values differ, dB versus dBA.

Based on the extensive literature and the physical tests performed, apparatus for determining the efficiency of cup cushions can be used effectively to apply theory in the design of ear muffs. From the data obtained by using this method, it is possible to calculate with reasonable accuracy some psychophysical quantities that are related to the effect of noise reduction by ear muffs.

Vignette

5. EAR MUFF ATTENUATION TESTS IN MINES

A study was undertaken to measure ear muff attenuation in mines.

5.1. Objective of the Study

The only certain means for evaluating the efficiency of the hearing protection program, equipment, training and supervision, is to measure, periodically, the hearing thresholds of all miners exposed to noise (32). However, this method does not detect problems until some hearing loss has occurred.

Because of this a new method is being developed in the Elliot Lake Laboratory. This method will provide an assessment of attenuation efficiencies of ear muffs in use. The tests carried out involved both the ear muffs already in use by the men and some of the types used in the laboratory tests described earlier.

5.2. Experimental Method

The Noise Dosimeter Vest's technical solution provides for the determination of the noise exposure index and the attenuation of ear muffs (Fig. 18). It does so under the most difficult working conditions (i.e., single platform (giraffe), the load-haul-dump (LHD) vehicle etc.).

The noise dosimeter vest has two noise dosimeters. Ear clips and helmet fasteners, with cables, preamplifiers and microphones, are contained in the pockets beside the dosimeters. Ear clips should be coloured differently according to intended use inside or outside an ear muff.

The surveyor must measure the distance between the bony structures just forward of the ears (bizygomatic diameter) using an outside caliper.

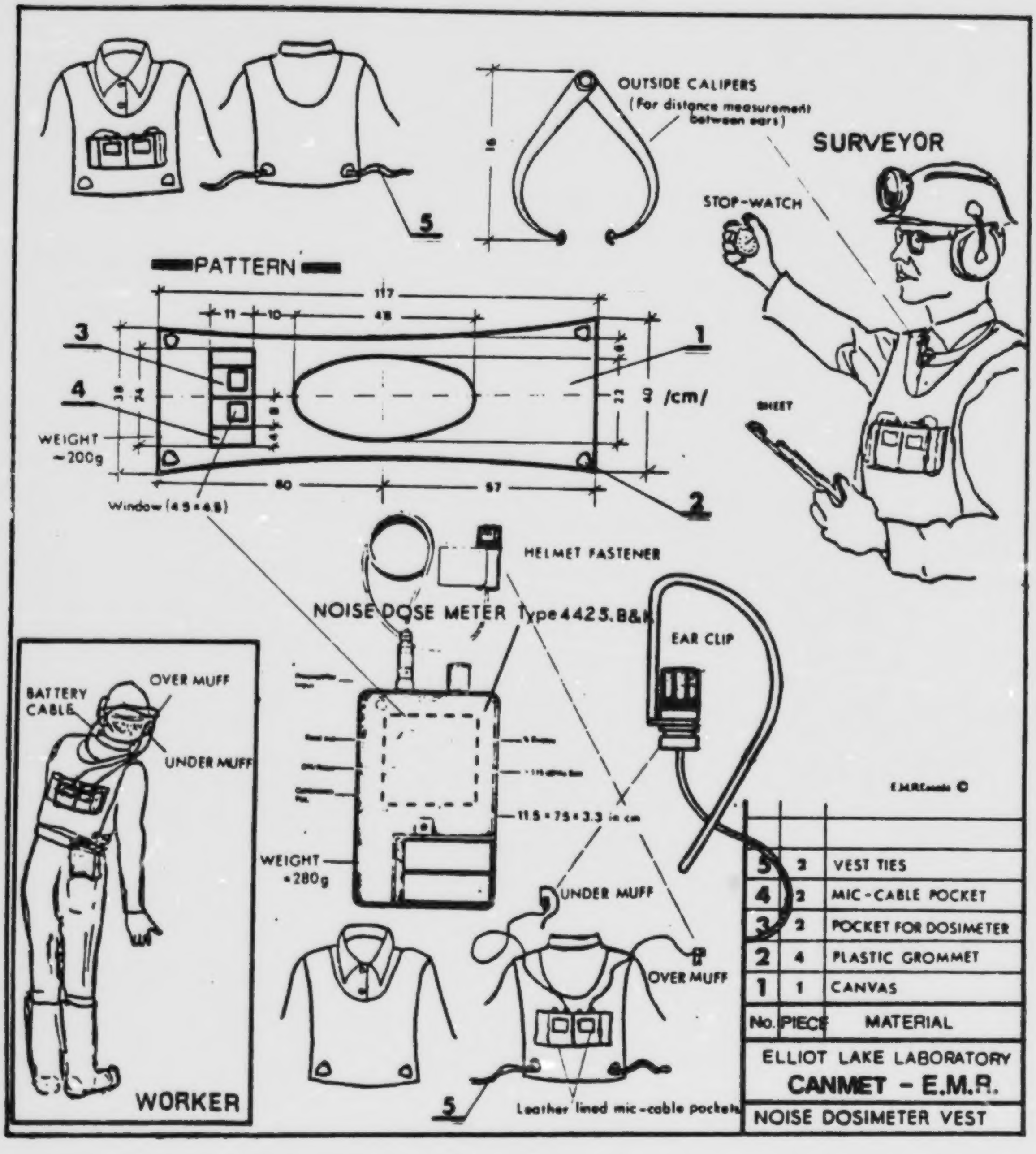

OUTSIDE CALIPERS
(For distance measurement between ears)
16
SURVEYOR
STOP-WATCH
SHEET
5
PATTERN
117
11
10
48
3
1
4
/cm/
WEIGHT ~200g
Window (4.5 × 4.8)
80
57
2
HELMET FASTENER
NOISE DOSE METER Type 4425. B&K
EAR CLIP
BATTERY CABLE
OVER MUFF
UNDER MUFF
11.5 × 7.5 × 3.3 in cm
WEIGHT ≈280g
UNDER MUFF
OVER MUFF
5
Leather lined mic-cable pockets
WORKER
EMRCanada ©
5 2 VEST TIES
4 2 MIC-CABLE POCKET
3 2 POCKET FOR DOSIMETER
2 4 PLASTIC GROMMET
1 1 CANVAS
No. PIECE MATERIAL
ELLIOT LAKE LABORATORY
CANMET - E.M.R.
NOISE DOSIMETER VEST

Fig. 18: The noise dosimeter vest in use during ear muff attenuation measurements.

The measurement of this distance is entered on the right hand side of the Ear Muff Noise Attenuation Survey Form (Appendices D-1, D-2 and D-3). On the basis of bizygomatic diameter measurements, the clamping force can be evaluated. For the immediate measurement clamping force in mines, the apparatus was designed in the Elliot Lake Laboratory (Appendix E-4). The full procedure for measurements and evaluations of the noise exposure index and ear muff noise reduction can be seen in the Ear Muff Noise Attenuation Survey Forms. Evaluations are done on the spot and the worker is immediately informed about the noise exposure index level and ear muff attenuation data. If the attenuation is unsatisfactory, the cause will have to be investigated. This investigation may be done on the spot in some cases, or in the laboratory. Results are filed in the office.

5.3. Participants

In this study one man at each of three working sites was chosen:

1. Jumbo (Three Drills) Operator,
2. Drill Hydrofore Operator, and
3. Jaw Crusher Operator.

Of particular importance were the following items:

- The miner is informed of the test's objective.
- The miner is asked to adjust his own ear muffs to his particular liking, and to make qualitative evaluations of comfort before and after the test.
- If a miner wishes to withdraw at any time and for any reason, he may do so.

It was explained that all testing would be conducted under the full support of miners and supervisory personnel.

5.4. Results

The results of the study indicate poor attenuation of ear muffs in underground mining conditions. As a result of analyzing the data obtained, three major findings are presented below.

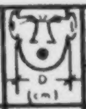
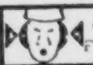
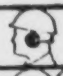
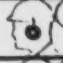
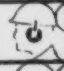
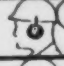
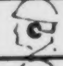
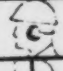
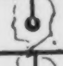
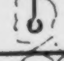
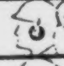
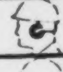
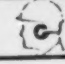
The Model 290-S Safe-T-Ear Muffs (No. 7 and 8) were designed to be worn with the suspension over the head, thus making it impossible to wear a helmet at the same time. Because of this they could not be tested. The clamping forces were calculated in the laboratory on the basis of measured bizygomatic diameters (Appendix E-2).

Jumbo (Three Drills) Operator: While working, the jumbo operator used only ear-plugs. The miner was of the opinion that his ear muffs were inefficient and wore them only because regulations required it. The ear muff was a Mark IV, M.S.A., model, with hat mounting, that could not properly cover the ears. On the basis of obtained results, it is evident that the noise levels are high (115 dBA) and that the ear muffs supplied do not offer adequate protection (Table 16). The test results show that this jumbo operator had very ill-fitting hat mounted ear muffs. The ear muffs with adequate attenuation were Nos. 1, 2, 5 and 10. In all cases, one of the factors contributing to the jumbo operator's problem was his extremely small head size. The jumbo operator judged ear muffs which are worn behind the head (Nos. 6 and 11) as poor providers of comfort. Also, such ear muffs have poor attenuation (Table 16).

Drill Hydrofore Operator: Hydraulic drills are used increasingly on jumbo machines, replacing the heavy pneumatic rock drills. There are many

TABLE 16

Attenuation of Ear Muffs at the Jumbo Operator's Station

No.	Ear Muff	Band	JUMBO (THREE DRILLS) OPERATOR									
			[illegible]	 D (cm)	 Clamping Force (gwt)			Attenuation (dBA)			Leq (dBA)		
					L.S.●	R.S.●	B.S.●	L.S.	R.S.	A.e.	L.S.	R.S.	A.e.
1	Model 1675, Amer. Optical, U.S.A.		◒	12.8	-	-	430	20.8	14.2	18.6	115.5	115.1	115.3
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.	 ①	◒	12.8	530	230	760	14.4	17.9	16.49	115	114.8	114.9
3	Helmet Muffs -(HF), Bilsom, Sweden.	 ②	●	12.8	580	630	1210	11.3	11.7	11.5	114.1	113.8	113.95
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	 ③	◒	12.8	930	1030	1960	12.3	14.6	13.6	116	112.9	114.45
5	Model NO NOISE Hellberg, Sweden.		◒	12.8	-	-	1830	28	20.2	25.6	117	117.6	117.3
6	Model Mark IV, MSA, U.S.A.		●	12.8	-	-	1080	9.6	7.2	8.56	111.4	116.4	115.4
7	Model 256-S Safe-T-Earmuff (gray), Safety Supply Co., Canada.		-	12.8	-	-	1130	-	-			-	
8	Model 256 S Safe-T-Earmuff (yellow) Safety Supply Co., Canada.		-	12.8	-	-	1030	-	-			-	
9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.	 ④	●	12.8	630	730	1360	4.8	0.6	3.1	115	112.1	113.55
10	Model E-305 Straightaway, D. Clark, U.S.A.		○	12.8	-	-	1230	~25	~25	~25	109.7	116.2	112.95
11	Sound Barrier EM 152, Willson, U.S.A.		●	12.8	-	-	830	11.5	12	11.75	114.3	115.8	115.05
	Mean	-	-	12.8	-	-	1168	-	-	-	114.55	114.97	114.76
	Std. Dev.	-	-	-	-	-	443	-	-	-	2.01	1.77	1.27
	$\overline{SPL}^{x}$	-	-	-	-	-	-				114.9	115.3	115.1

MINE STANDARD IN USE

NOTE: + Evaluation ● Satisfactory (1) ◒ Good (2) ○ Very Good (3)

● L.S. - Left Side; R.S. - Right Side; B.S. - Both Sides

x Average $\overline{SPL} = 10 \log \frac{1}{n} (\text{antilog} \frac{SPL_1}{10} + \text{antilog} \frac{SPL_2}{10} + \dots + \frac{SPL_n}{10})$

① Tested while mounted on helmet; 905 ERB Plastics, Inc., Woodstock CA, 905.

② Tested while mounted on helmet; Classe C, CSA Standard Z94.1

③ Tested while mounted on helmet; Safety Supply Company, Rain-Guard, Safe-T-Cap, CSA Standard Z94.1

④ Tested while mounted on helmet; Hard Boiled, E.D. Bollard Co., S.F., U.S.A.

reasons why the hydraulic percussion rock drill is better, e.g., faster penetration, longer parts life, better drilling control, improved efficiency, no fog, and lower noise levels (one boom creates noise levels of only 105 dBA) etc. (33). An hydrofore drill (hydraulic-electric fan) has no air exhaust noise and thus produces low noise levels at low frequencies. Because the attenuation of ear muffs is better at high frequencies, it should be expected that their efficiencies will be very high.

Test results demonstrate that the better attenuations are obtained by ear muff Nos. 5, 6 and 10 (Table 17). All three muffs were worn behind the head. The remaining ear muffs did not provide satisfactory attenuations.

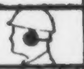
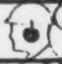
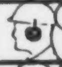
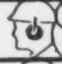
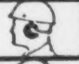
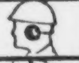
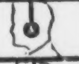
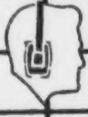
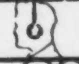
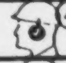
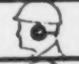
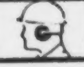
Jaw Crusher Operator: Generally speaking, ear muffs should be used where the ambient sound levels exceed 105 dBA. Below this value ear plugs give good protection. Because ear muffs are practical for intermittent noise (and because infection can result from the use of earplugs), usually only ear muffs are used to protect from lower noise levels in all areas of mines. Test results from eight ear muffs show sufficient attenuation, 90 dBA and below (Table 18). Only ear muff No. 9 has a very low attenuation (8.3 dBA). Once again, extremely good attenuation is provided by three muffs: No. 5 (18.8 dBA), No. 6 (23.8 dBA) and No. 10 (23.1 dBA).

5.5. Clamping Force and Comfort

On the average, ear muffs have poor attenuation (~ 15 dBA). Thus ear muffs and ear-plugs should be used in tandem. The efficiency of an ear muff is determined by its clamping force and its fit over the ear. If the clamping force is decreased, attenuation also decreases. Clamping force

TABLE 17

Attenuation of Ear Muffs at the Drill Hydrofore Operator's Station

No.	Ear Muff	Band	DRILL HYDROFORE OPERATOR										
			Comfort +	D (cm)	Clamping Force (gwt)			Attenuation (dBA)			L$_{eq}$ (dBA)		
					L.S.●	R.S.●	B.S.●	L.S.	R.S.	Ave.	L.S.	R.S.	Ave.
1	Model 1675, Amer. Optical, U.S.A.		●	13.8	-	-	580	13.5	11.5	12.6	103.8	106.2	105
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.	 ①	○	13.8	680	380	1060	11.4	12.6	12.04	104.3	107.1	105.7
3	Helmet Muffs -(HF), Bilsom, Sweden.	 ②	●	13.8	630	680	1310	10.3	4.2	8.25	106.6	106.9	106.7
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	 ③	○	13.8	1030	1080	2110	11.5	9.1	10.46	104.8	104.6	104.7
5	Model NO NOISE, Hellberg, Sweden.		○	13.8	-	-	2080	27.2	21.7	25.26	104.2	108.7	106.4
6	Model Mark IV, MSA, U.S.A.		◒	13.8	-	-	1230	25.6	23.4	24.64	104.3	102.3	103.3
7	Model 25[illegible]-S Safe-T-Earmuff (gray). Safety Supply Co., Canada.		-	13.8	-	-	1230	-	-			-	-
8	Model 256 S Safe-T-Earmuff (yellow) Safety Supply Co., Canada.		-	13.8	-	-	1130	-	-			-	-
9	Model E-795 Straightaway Helmet Muffs, D. Clark, U.S.A.	 ④	◒	13.8	680	880	1560	6.4	5.1	5.80	104.9	103.3	104.1
10	Model E-805 Straightaway, D. Clark, U.S.A.		◒	13.8	-	-	1380	15.8	19.8	18.24	102.8	103.3	103.0
11	Sound Barrier EM 152, Willson, U.S.A.		○	13.8	-	-	930	10.4	9.5	9.97	104.9	103.9	104.4
	Mean	-	-	13.8	-	-	1327	-	-	-	104.5	105.1	104.8
	Std. Dev.	-	-	-	-	-	456	-	-	-	1.00	2.17	1.2
	$\overline{SPL}^x$	-	-	-	-	-	-				104.6	105.6	105.1

MINE STANDARD IN USE

NOTE: + Evaluation ● Satisfactory (1) ◒ Good (2) ○ Very Good (3)

● L.S. - Left Side; R.S. - Right Side; B.S. - Both Sides

x Average $\overline{SPL} = 10 \log \frac{1}{n} (\text{antilog} \frac{SPL_1}{10} + \text{antilog} \frac{SPL_2}{10} + \dots + \frac{SPL_n}{10})$

① Tested while mounted on helmet; 905 ERB Plastics, Inc., Woodstock CA. 905.

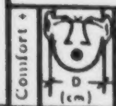
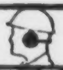
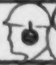
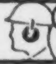
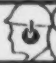
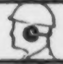
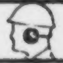
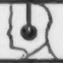
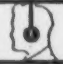
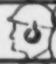
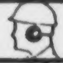
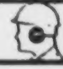
② Tested while mounted on helmet; Classe C, CSA Standard Z94.1

③ Tested while mounted on helmet; Safety Supply Company, Rain-Guard, Safe-T-Cap, CSA Standard Z94.1

④ Tested while mounted on helmet; Hard Boiled, E.D. Bollard Co., S.F., U.S.A.

TABLE 18

Attenuation of Ear Muffs at the Jaw Crusher Operator's Station

No.	Ear Muff	Band	JAW CRUSHER OPERATOR										
			Comfort +	 D (cm)	Clamping Force (gwt)			Attenuation (dBA)			Leq (dBA)		
					L.S.●	R.S.●	B.S.●	L.S.	R.S.	Ave.	L.S.	R.S.	Ave.
1	Model 1675, Amer. Optical, U.S.A.		○	13.5	-	-	560	~15	~15	15	101.7	101.3	101.5
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.	 ①	●	13.5	580	330	910	4.7	13.8	11.25	97.4	100.9	99.15
3	Helmet Muffs -(HF), Bilsom, Sweden.	 ②	●	13.5	630	680	1310	9.8	10.8	10.35	100.4	103.6	102
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.	 ③	●	13.5	980	1080	2060	14.3	6.8	12	102.5	101.8	102.15
5	Model NO NOISE, Hellberg, Sweden.		⊖	13.5	-	-	1980	18.4	19.2	18.82	102.2	101.3	101.75
6	Model Mark IV, MSA, U.S.A.		⊖	13.5	-	-	1180	18	26.2	23.6	95.7	100.9	100.3
7	Model 290-S Safe-T-Earmuff (gray), Safety Supply Co., Canada.		-	13.5	-	-	1180	-	-			-	-
8	Model 290 S Safe-T-Earmuff (yellow) Safety Supply Co., Canada.		-	13.5	-	-	1080	-	-			-	-
9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.	 ④	●	13.5	680	830	1510	7.4	9.0	8.27	100.3	103.7	102
10	Model E-805 Straightaway, D. Clark, U.S.A.		○	13.5	-	-	1330	22.8	23.4	23.11	95.9	98.6	97.25
11	Sound Barrier EM 152, Willson, U.S.A.		⊖	13.5	-	-	880	17.8	13.4	16	100	103.4	101.7
	Mean	-	-	13.5	-	-	1273	-	-	-	100.0	101.7	100.87
	Std. Dev.	-	-	-	-	-	447	-	-	-	2.18	1.65	1.68
	$\overline{SPL}^x$	-	-	-	-	-	-	-	-	-	100.44	101.98	101.28

MINE STANDARD IN USE

NOTE: + Evaluation ● Satisfactory (1)
⊖ Good (2)
○ Very Good (3)

● L.S. - Left Side; R.S. - Right Side; B.S. - Both Sides

x Average $\overline{SPL} = 10 \log \frac{1}{n} (\text{antilog} \frac{SPL_1}{10} + \text{antilog} \frac{SPL_2}{10} + \cdots + \frac{SPL_n}{10})$

① Tested while mounted on helmet; 905 ERB Plastics, Inc., Woodstock CA, 905.

② Tested while mounted on helmet; Classe C, CSA Standard Z94.1

③ Tested while mounted on helmet; Safety Supply Company, Rain-Guard, Safe-T-Cap, CSA Standard Z94.1

④ Tested while mounted on helmet; Hard Boiled, E.D. Bollard Co., S.F., U.S.A.

will vary in each case because of different head sizes (Tables 16, 17 and 18). A good fit over the ear is an important factor for noise attenuation, and it is inter-related with comfort. From the tests performed it is evident that comfort and attenuation affect one another (Table 19).

Characteristically, ear muffs mounted on the hat and worn behind the head have different comfort evaluations and different attenuation results (Nos. 4, 5, 9 and 10). In all cases, hats cause these discrepancies. There are other numerous causes: poor mounting due to insufficient instructions, varying head dimensions and ear heights, improper fitting, interference by hair or eye-glasses, improper wearing of ear muffs, etc. Because of this the value of a measured attenuation in use does not equal the value of a theoretical attenuation (noise reduction) (Table 19).

Clamping force studies were made with eleven and ten ear muffs (Table 20).

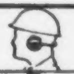
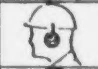
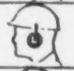
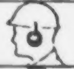
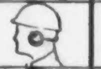
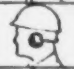
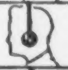
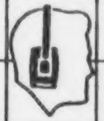
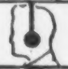
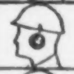
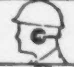
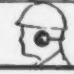
Ear Muffs	Mean Clamping Force $\overline{X}$ (g wt)	Number of Observations n	Standard Deviation σ (g wt)
11	1256	33	440
10	1264	30	461

Because the number of observations is sufficiently large (say, $n \geq 30$), a close estimate of the standard deviation σ_d is possible. The significance of the difference of means $(\overline{X})$ is measured by the ratio of the difference to its standard deviation (S), namely (17):

$$Z = \frac{(\overline{X}_1 - \overline{X}_2)}{\sigma_d} \qquad \text{(Eq. 5)}$$

TABLE 19

Summary of Comfort, Attenuation and Theoretical Attenuation Survey Data

No.	Ear Muff	Band	Comfort⁺				Attenuation (dBA)				Theoretical Attenuation (dBA)*			
			Jumbo Operatr	Hydro. Operatr	Crusher Operatr	Σ	Jumbo Operatr	Hydro. Operatr	Crusher Operatr	Σ/3	Jumbo Operatr	Hydro. Operatr	Crusher Operatr	Σ/3
1	Model 1675, Amer. Optical, U.S.A.		◒	●	○	6	18.6	12.6	15	15.4	26.9	28.8	27.7	27.5
2	Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.		◒	○	●	6	16.5	12	11.3	13.3	23.1	25.5	24.1	24.2
3	Helmet Muffs - (HF), Bilsom, Sweden.		●	●	●	3	11.5	8	10.3	9.9	27.8	29.6	28.6	28.7
4	Model NO NOISE Helmet Muffs, Hellberg, Sweden.		◒	○	●	6	13.6	10.5	12	12	28.2	29.9	29	29
5	Model NO NOISE, Hellberg, Sweden.		◒	○	◒	7	25.7	25.3	18.8	23.3	29.4	30.9	30.4	30.2
6	Model Mark IV, MSA, U.S.A.		●	◒	◒	5	8.6	24.6	23.8	19	30.6	31.4	31.3	31.1
7	Model 290-G Safe-T-Earmuff (gray), Safety Supply Co., Canada		-	-	-	-	-		-	-	(34.6)	(36.3)	(35.4)	(35.4)
8	Model 290-S Safe-T-Earmuff (yellow), Safety Supply Co., Canada		-	-	-	-	-		-	-	(34.6)	(36.3)	(35.4)	(35.4)
9	Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.		●	◒	●	4	3.2	5.8	8.3	5.8	28.5	29.9	29.3	29.2
10	Model E 305 Straightaway, D. Clark, U.S.A.		○	◒	○	8	25	18.2	23.1	22.1	27.9	30.1	28.9	29
11	Sound Barrier EM 152, Willson, U.S.A.		●	○	◒	6	11.8	10	16	12.6	29	30.2	29.8	29.7

MINE STANDARD IN USE

⁺ Evaluation: ● Satisfactory (1)
◒ Good (2)
○ Very Good (3)

* Appendix A-1, Computer Program

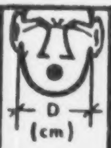
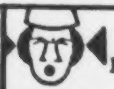
Noise Surveys in Mines

Measured at the Operator's Ears	Frequency (Hz)									dBA*
	31.5	63	125	250	500	1000	2000	4000	8000	
Jumbo (Three Drills)	89	100	109	109	109	107	108.5	109.5	106	115.24
Drill Hydrofore	68	79	86	99	96	99	99	99	94	105.2
Jaw Crusher	89	94	94.5	94.5	94.5	94.5	94	97	88	101.64

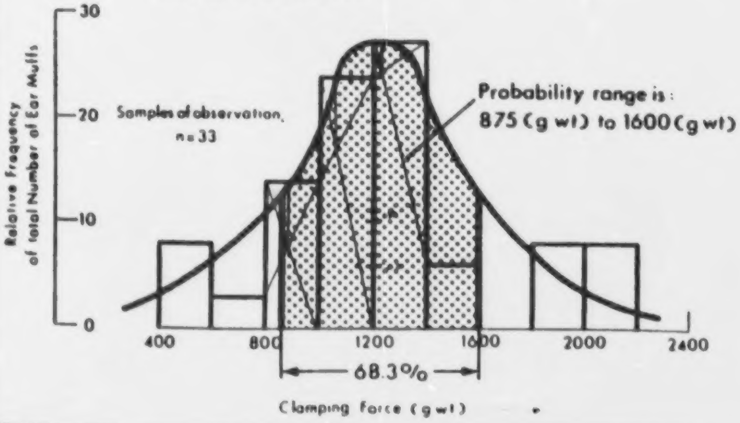
* Total noise estimated from the octave-band noise levels given in the first nine columns.

TABLE 20

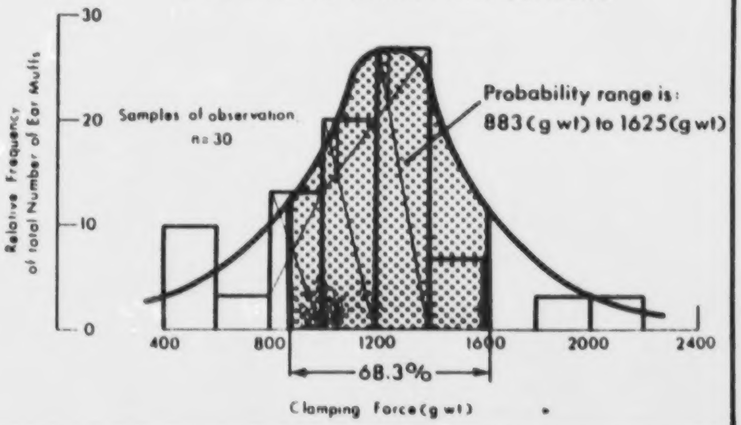
Summary of Clamping Force Survey Data

Type of Equipment	 D (cm)	 Clamping Force (gwt)		Mean	Std. Dev.	Number of Items					
						Clamping Force (g wt)					Σ
		Lower	Upper			400-800	800-1200	1200-1600	1600-2000	>2000	
Jumbo (3 Drills) Operator	12.8	430	1960	1168	443	2	4	3	2	-	11
Drill Hydrofore Operator	13.8	580	2110	1327	456	1	3	5	-	2	11
Jaw Crusher Operator	13.5	580	2060	1273	447	1	6	3	-	1	11
Average	13.4	430	2110	1256	440	4	13	11	2	3	33

ELEVEN EAR MUFFS



TEN EAR MUFFS (without No. 7 Ear Muff)

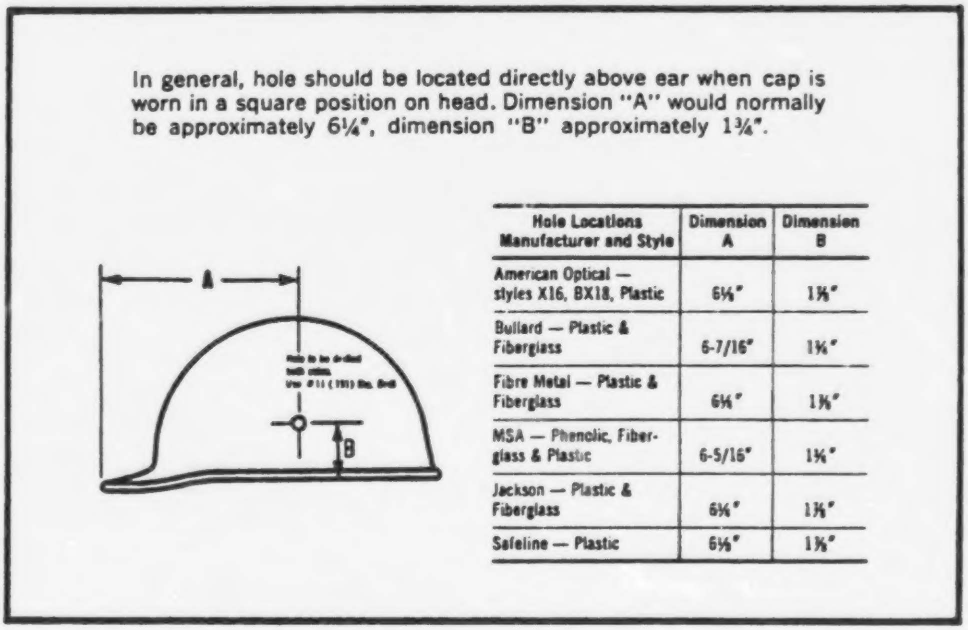


where: Z = a standardized variable and is a dimensionless quantity (i. e., is independent of units used),

and, $$\sigma_d^2 \bumpeq \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2} \qquad \text{(Eq. 6)}$$

This is a one-sided test, since we are checking the null hypothesis $\overline{X}_1 = \overline{X}_2$ $\overline{X}_1 > \overline{X}_2$. We find the probability of obtaining by chance a value of Z of at least this magnitude as (0. 5000 - 0. 0279) = 0. 4721 = 47. 21 percent. We conclude, that the observed difference in means of the clamping forces considering eleven muffs or ten muffs, could occur by random variation in 94. 42 percent of the observations. Therefore the difference is not significant but due to chance error within 5. 58 percent, which is trivial. The clamping forces vary from 430 (g wt) to 2110 (g wt). The mean value is 1256 ± 77 (g wt) (Standard error is ± 77 (g wt))(Table 20). In various references in the literature it can be found that a clamping force can vary between 500 and 1000 grams (34). Many manufacturer's catalogues contain no information about clamping forces. Only the Mark IV, MSA, model's specifications claim that the head pressure (clamping force) is, at 14. 2 cm: 1191 (g wt) (35). According to the calculated mean, this would correspond to 1256 - 77 = 1179 (g wt) at 13. 4 cm. The data in the literature differs from practical data. Manufacturers have increased clamping forces in their products thus creating discomfort for the wearer. They did this because they are well aware that too small a pressure results in the creation of air leaks.

A bad connection between the helmets and the cups hinders clamping force and comfort. Poor mounting of assymmetrical ear muffs is caused by two things; a shortage of manufacturer's data for hole locations on helmets and the poor mounting of ear muffs on helmets in mines. Only American Optical has holes located in different places for different helmets (Fig. 19) (36). Some of the biggest manufacturers of ear muffs produce helmets and stipulate the joint sale of ear muffs and helmets.



In general, hole should be located directly above ear when cap is worn in a square position on head. Dimension "A" would normally be approximately 6¼", dimension "B" approximately 1¾".

Hole Locations Manufacturer and Style	Dimension A	Dimension B
American Optical — styles X16, BX18, Plastic	6⅛"	1⅝"
Bullard — Plastic & Fiberglass	6-7/16"	1¾"
Fibre Metal — Plastic & Fiberglass	6¼"	1⅝"
MSA — Phenolic, Fiberglass & Plastic	6-5/16"	1¾"
Jackson — Plastic & Fiberglass	6¼"	1⅝"
Safeline — Plastic	6⅛"	1⅝"

Fig. 19: Hole locations in helmets (36).

The best solution is to use a support strap in conjunction with a safety helmet (Fig. 20). The strap provides support for all ear muff type protectors when worn behind the head (back-band with strap). This head-strap is adjustable over the head to avoid discomfort caused by the pull of gravity on the ear cups. It also holds the ear cups in position over the ears. Helmets need not be drilled or tampered with. Loss of attenuation is minimal.

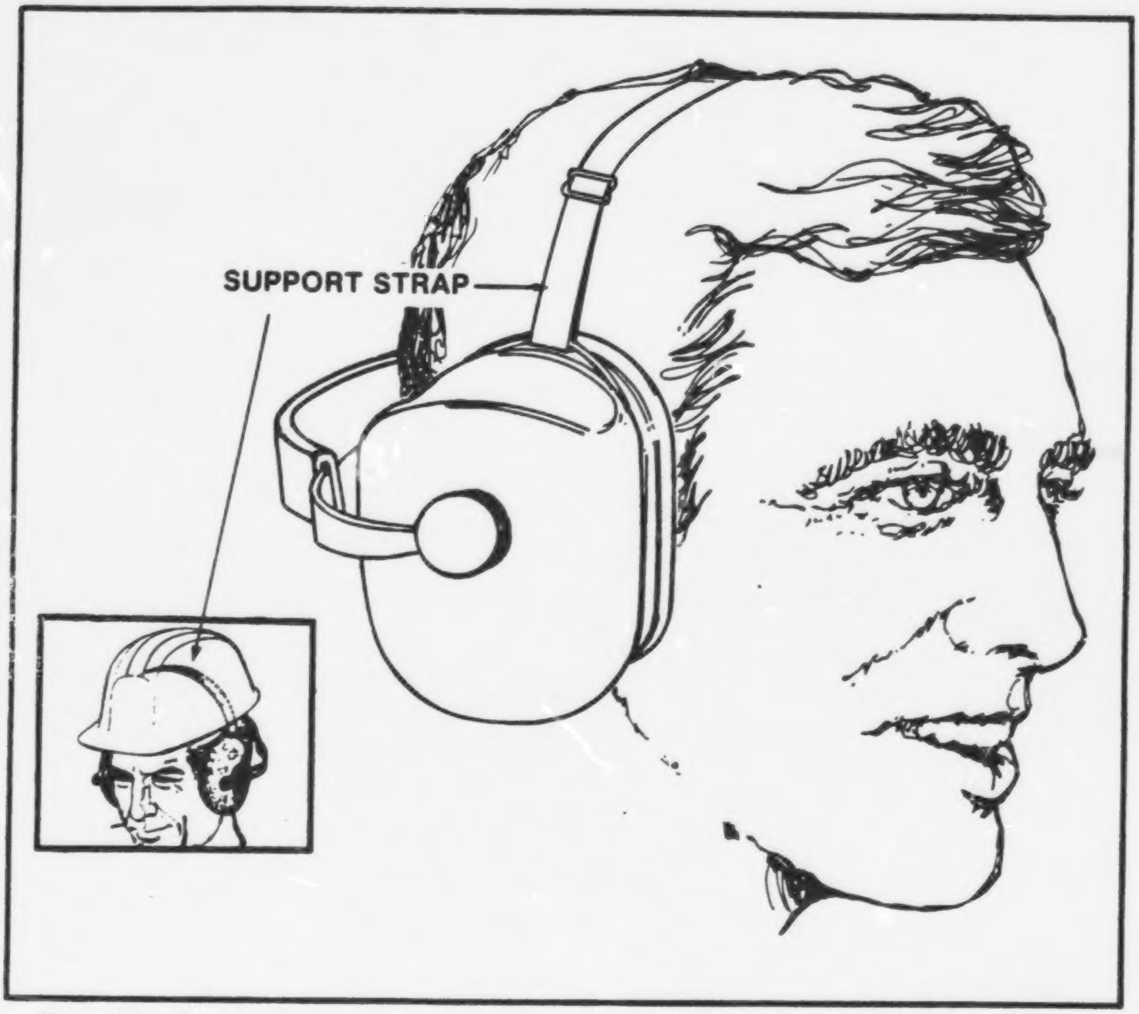
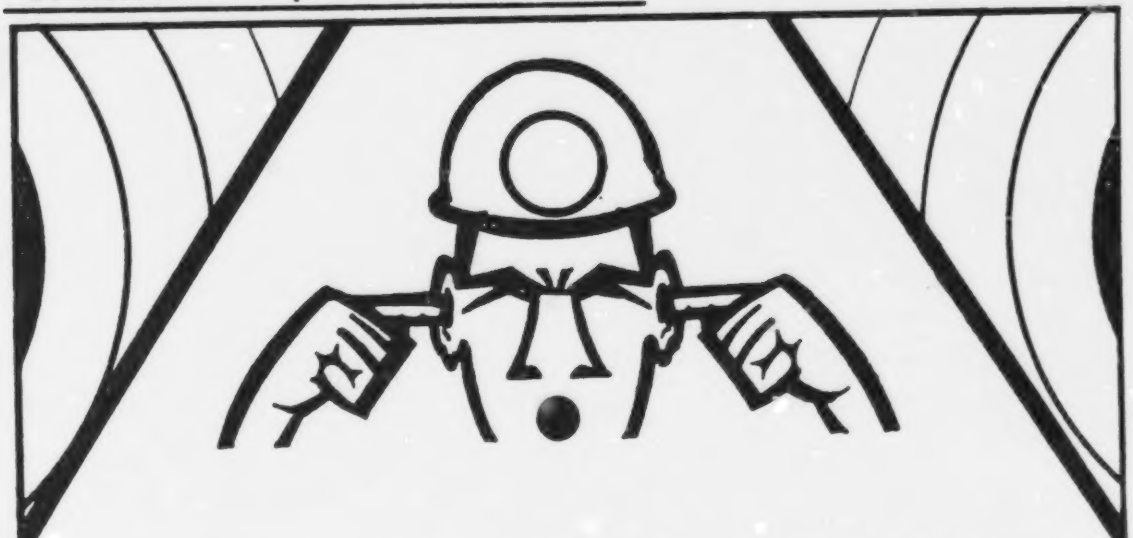


Fig. 20: Support strap: adjustable, lightweight, easily adaptable and comfortable (37) (38).

5.6. Discussion

Assuming that ear muffs are excellent attenuators (which they are not), and that a miner is working under noise levels of 115 dBA (Jumbo-Three Drills), then he would have to wear his muffs 95 percent of the drilling time to lower his exposure to within the 85 or 90 dBA limit. Taking his muffs off for 12 minutes in a four hour drilling period would over-expose the miner to noise. Most hearing loss occurs in the first five years of exposure to noise (39). A man who has worked in noisy environments for 25 years gains no practical benefit from even the most powerful muffs (40). Of course, safety organizations in mines must be capable of performing the task of controlling attenuation of ear muffs.

Two types of safety organizations exist in Canadian mines. The first is in effect in smaller mines and safety is the specific responsibility of all management. Staff safety organizations are used at medium and large mines. The safety program is headed by supervisory personnel. They are not responsible for production and should not give orders to miners. It is considered that the foreman is the key to the entire accident prevention problem. He is in the best position to put safety into practice, and must become capable in doing so through experience and training. Miners must be induced to co-operate in the training.



Vignette

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Exposure to noise of sufficient intensity for long periods of time can produce detrimental changes in the inner ear and decrease the ability to hear. Noise pollution has been recognized as a hazardous problem in Canadian mines and mills. Mechanization in mines has resulted in higher noise levels. Persons operating machines that produce excessive noise, and miners in close proximity, are exposed to high noise levels. These miners are required unconsciously to make use of their decision - making abilities in determining the effects of noise on peripheral vision, the amount of muscle tension required to do the task, spatial positioning of the head, the processing of communicative information, and other aspects of performance. An analysis showed that Canada has made great efforts in the abatement of noise in mines. The high cost of fully implementing a 90 dBA noise standard, and to comply with the 85 dBA noise standard, requires that we develop very inexpensive and very effective methods in the battle against noise in mines.

The most important function of an ear muff is that it will attenuate noise whilst providing a comfortable fit. Manufacturers claim that ear muffs are shaped to fit all ears comfortably; this is not always the case. Some of the main problems encountered in ear muffs are caused by the ear cushion seal against the head and their functional design. In comfort tests it was demonstrated that ear muffs with large area of cushions were favoured (Tables 3 and 4).

The noise levels reaching the ears were calculated by a computer model for ear muffs fitted by either the octave-band or the sound level conversion method. The method provides an acceptable basis for selecting ear muffs in any industrial noise spectrum not dominated by intense pure tone or narrow-band energy components.

Methods using short measurements for the determination of a noise exposure index, and modes of control for good muff wearing, were developed in the Elliot Lake Laboratory. Tests in mines showed that only three ear muffs of all examined have good attenuations (Table 19):

- No. 5 Model NO NOISE, Hellberg, Sweden (23. 3 dBA);
- No. 6 Model Mark IV, MSA, U.S.A. (19 dBA); and
- No. 10 Model E-805 Straightaway, D. Clark, U.S.A. (22.1 dBA).

All three ear muffs are worn behind the head. The No. 10 muff has a support strap which improves comfort and maintains a good fit during wear. Causes of poor attenuation are numerous: bad mounting of ear muffs on helmets, improper fitting, interference by hair and eyeglasses, improper wearing by miners, unsatisfactory enforcement by supervisory personnel, incomplete training of miners, etc.

Laboratory tests showed that a difference in attenuation between muffs, and a difference between attenuation characteristics from factory (ANSI Z 24.22-1957) and laboratory tests exist. The best result was shown by the No. 10 Model, E-805 Straightaway, D. Clark, U.S.A. (see pages 53, 56 and 66). There is no agreement in attenuations between laboratory tests and field tests.

Results of this research have indicated that none of the currently manufactured ear muffs tested in this study contain all of the characteristics desirable in an ideal unit.

Today, in Canadian mines, ear muffs are a part of safety equipment such as helmets, masks, safety glasses, gloves and safety boots. Because of this a new effort has been made to obtain a detailed analysis of ear muffs to improve their application under working conditions.

6.2. Recommendations

1. The results suggest that obligatory tests, which were developed in the Elliot Lake Laboratory for ear muff attenuation, should be introduced. These tests require only two dosimeters and a stop watch. Dosimeters have the small sized microphones and very accurate short time readings of the noise exposure index. Also, a pocket-sized computer designed for sound amplitude analysis should be utilized (dBA, L_{eq}, L_{max} and time duration of the sampling period) (41). Portable instruments that monitor the real attenuation of ear protectors while worn at the work station, exist on the market. These instruments are impractical in mines because they slow down the normal work pace, thus changing the noise level (42).
2. Because of unsatisfactory ear muff attenuation in working conditions, it should be a mandatory requirement that workers wear ear muffs and ear plugs only if the noise level is higher than 105 dBA (various references in the literature recommend 110 dBA).
3. It is recommended that miners use support straps to maintain effective

attenuation and positioning of ear muffs which are worn behind the head. To convince the employee of the importance of a hearing conservation program requires planning, educational effort, persistent control and assistance.

4. Foremen must be capable, through experience and training, to help and control miners in their task of properly wearing ear muffs.
5. Introduce the program to new miners at the start of employment.
6. When purchasing ear muffs, practical attenuation results should be taken into account, because the greatest noise reduction is not always given by ear muffs which have the best attenuation characteristics in the laboratory.
7. Constant contact must be maintained with manufacturers to improve designs, maintenance, and servicing of ear muffs.

Vignette

7. ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Mines Accident Prevention Association of Ontario for providing a selection of ear muffs for this project. He is also indebted to Dr. R. Tervo and G. Knight, research scientists and Dr. N.K. Davé, research fellow, who were helpful in many ways. Grateful acknowledgement is given to A. Webster who transcribed and completed the tables from the raw data. He acknowledges the contribution of R. Regan for his assistance in the laboratory work and H. Poliquin for his assistance in field work.

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APPENDIX A

Programs

Computer Program for Calculating the Effective Noise Reduction (Attenuation) of Ear Muffs

```
 100 E=LOG(10)
 105 A1=0
 110 A2=0
 120 DIM F(9),L(9),C(9),A(9)
 130 F(1)=31.5
 140 F(2)=63
 150 F(3)=125
 160 F(4)=250
 170 F(5)=500
 180 F(6)=1000
 190 F(7)=2000
 200 F(8)=4000
 210 F(9)=8000
 220 C(1)=-39.4
 230 C(2)=-26.2
 240 C(3)=-16.1
 250 C(4)=-8.6
 260 C(5)=-3.2
 270 C(6)=0
 280 C(7)=1.2
 290 C(8)=.9
 300 C(9)=-1.2
 310 FOR I=1 TO 9
 320 READ A(I)
 330 NEXT I
 340 FOR J=3 TO 9
 350 READ L(J)
 360 A1=A1+EXP(E/10*(A(J)+C(J)-L(J)))
 370 A2=A2+EXP(E/10*(A(J)+C(J)))
 380 NEXT J
 390 A=INT(1000/E*LOG(A2)+.5)/100
 400 A0=INT(10*(A-10/E*LOG(A1))+.5)/10
 410 PRINT 'FREQ','NOISE LEVEL','NOISE REDUCTION'
 420 PRINT '(HZ)','(DB)','(DB)'
 430 PRINT
 440 FOR K=3 TO 9
 450 PRINT F(K),A(K),L(K)
 460 NEXT K
 470 PRINT
 480 PRINT 'NOISE LEVEL IN DBA:';A
 490 PRINT 'NOISE REDUCTION IN DBA:';A0
 500 DATA 89,109,109,109,109,107,108.5,109.5,106
 510 DATA 9.7,16.1,24.9,33.9,34.1,38.5,32.7
```

```
FREQ                     NOISE LEVEL          NOISE REDUCTION
(HZ)                     (DB)                 (DB)

 125                      109                  9.7
 250                      109                  16.1
 500                      109                  24.9
 1000                     107                  33.9
 2000                     108.5                34.1
 4000                     109.5                38.5
 8000                     106                  32.7

NOISE LEVEL IN DBA: 115.24
NOISE REDUCTION IN DBA: 26.9
```

Program
Calculate A-Weighted Sound Level from Octave Band Levels Using a Hewlett-Packard HP-35

Step No.	Enter Data	Operation		Step No.	Enter Data	Operation	
		Enter	Press			Enter	Press
1	$L_{31.5}$	-	ENTER↑	20	-	10	x^y
2	-	39.4	−	21	L_{1k}	-	ENTER↑
3	-	10	÷	22	-	10	÷
4	-	10	x^y	23	-	10	x^y
5	L_{63}	-	ENTER↑	24	L_{2k}	-	ENTER↑
6	-	26.2	−	25	-	1.2	+
7	-	10	÷	26	-	10	÷
8	-	10	x^y	27	-	10	x^y
9	L_{125}	-	ENTER↑	28	L_{4k}	-	ENTER↑
10	-	16.1	−	29	-	0.9	+
11	-	10	÷	30	-	10	÷
12	-	10	x^y	31	-	10	x^y
13	L_{250}	-	ENTER↑	32	L_{8k}	-	ENTER↑
14	-	8.6	−	33	-	1.2	−
15	-	10	÷	34	-	10	÷
16	-	10	x^y	35	-	10	x^y, +
17	L_{500}	-	ENTER↑	36	-	-	LOG
18	-	3.2	−	37	-	10	×
19	-	10	÷				

Note:

Step No. 1, for data beginning at 31.5 Hz octave band.
Step No. 5, for data beginning at 63 Hz octave band.
Step No. 9, for data beginning at 125 Hz octave band.

Program
Computation of Equivalent Continuous Sound Level (L_{eq})
Using a Hewlett-Packard HP-35

L_{eq} is defined mathematically by (Appendix F) (43):

$$L_{eq} = \frac{q}{\log_{10} 2} \log_{10} \left[\frac{1}{T} \int_0^T \left(\frac{p(t)}{p_o} \right)^{\frac{20 \log_{10} 2}{q}} dt \right] \qquad \text{(Eq. 7)}$$

The OSHA has $q = 5$, and

$$L_{eq} = 16.6 \log_{10} \left[\frac{1}{T} \int_0^T \left(\frac{p(t)}{p_o} \right)^{1.2} dt \right]$$

where: $dB = 10 \log \left(\frac{p}{p_o} \right)^2$ (Eq. 8)

or: $\frac{p}{p_o} = \sqrt{\text{antilog} \frac{dB}{10}}$

Evaluation:

Step No.	Enter Data	Operation		Step No.	Enter Data	Operation	
		Enter	Press			Enter	Press
1	L_{p1}	-	ENTER↑	9	-	-	LOG
2	-	10	÷	10	-	1.2	×
3	-	10	x^y, √	11	-	10	x^y
4	t_1	-	×	12	t_1	-	ENTER↑
4a	-	-	-	13	t_2	-	+
5	L_{p2}	-	ENTER↑	Repeat line 13 for all values of t_3, t_4, etc.			
6	-	10	÷				
7	-	10	x^y, √	14	-	-	÷ LOG
8	t_2	-	×, +	14a	-	-	-
8a	-	-	-	15	-	16.6	×
Repeat lines 5, 6, 7 and 8 for all values of L_p from L_{p3}, L_{p4}, etc. and t_3, t_4, etc.							

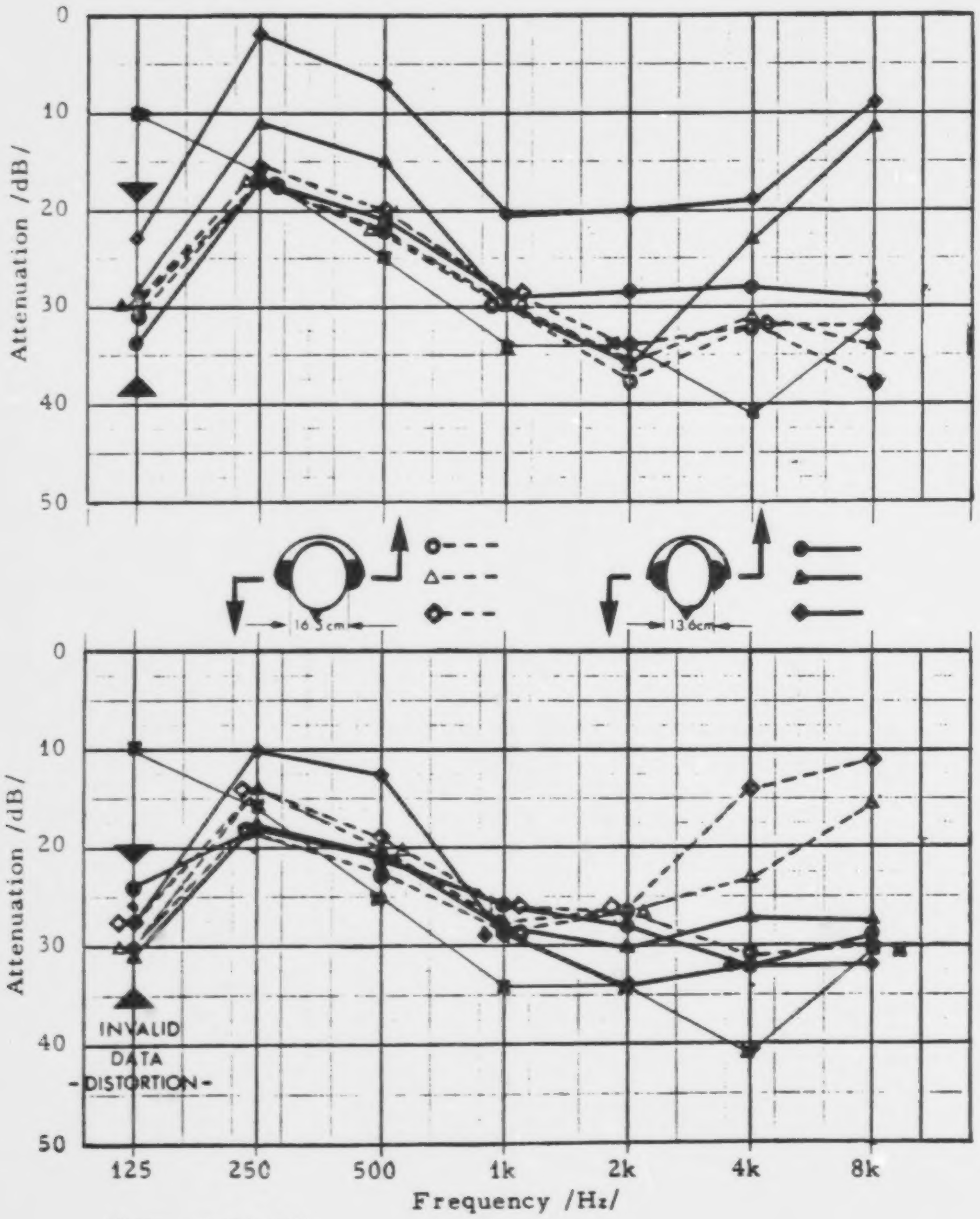
These computations assume that the sound level is constant for the time interval considered.

APPENDIX B

Psychophysical Test

1. Movement of the neck joint in normal position. Subjects used glasses and adapters.
   - a) Graphs with frequency in hertz (Appendices B-1 to B-11).
   - b) Table in dBA-network (Appendix B-12).
2. Neck joint flexion movement (dorsal and ventral) and neck rotation (right and left). Subjects used glasses.
   - a) Graphs with frequency in hertz (Appendices B-13 to B-22).
   - b) Table in dBA-network (Appendices B-23 and B-24).

No. 1 Model 1675, Amer. Optical, U.S.A.



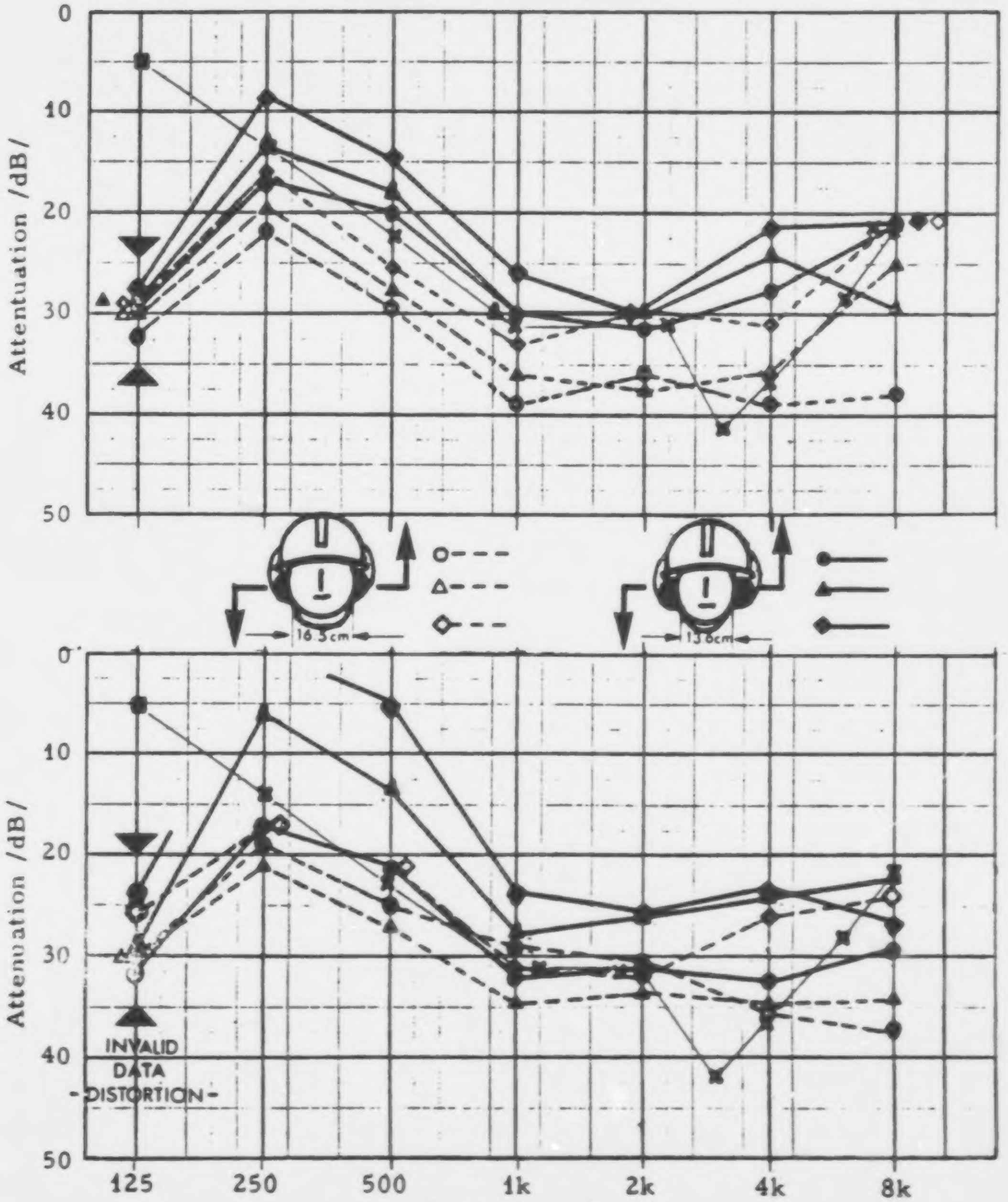
Note: ○ ● Muff.

△ ▲ Muff and Glasses.

◇ ◆ Muff, Glasses and Adapter.

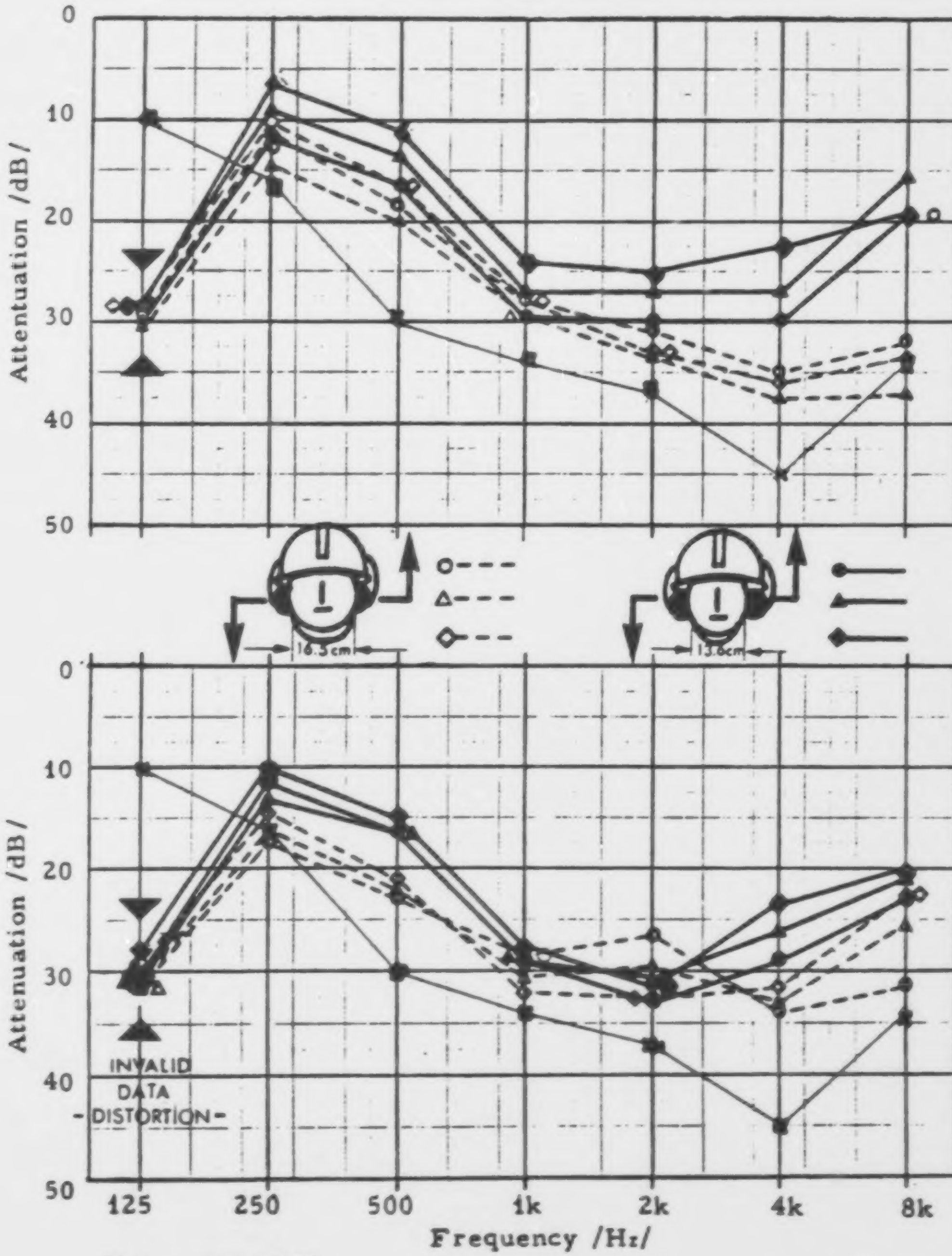
✱ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 2 Model 1750 Cap Mounted Hearing Protector
Amer. Optical, U.S.A.



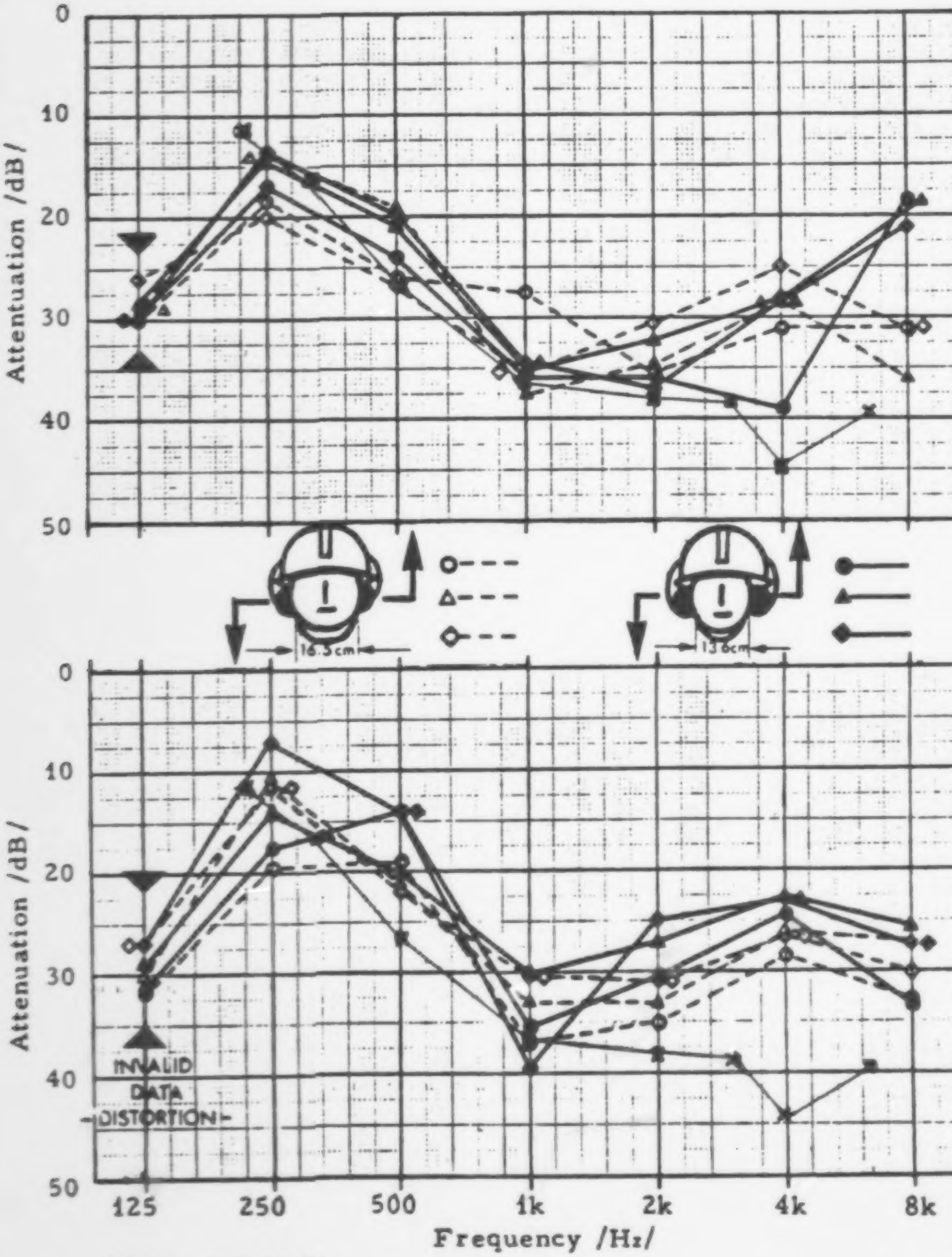
Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 3 Helmet Muffs - (HF), Bilsom, Sweden



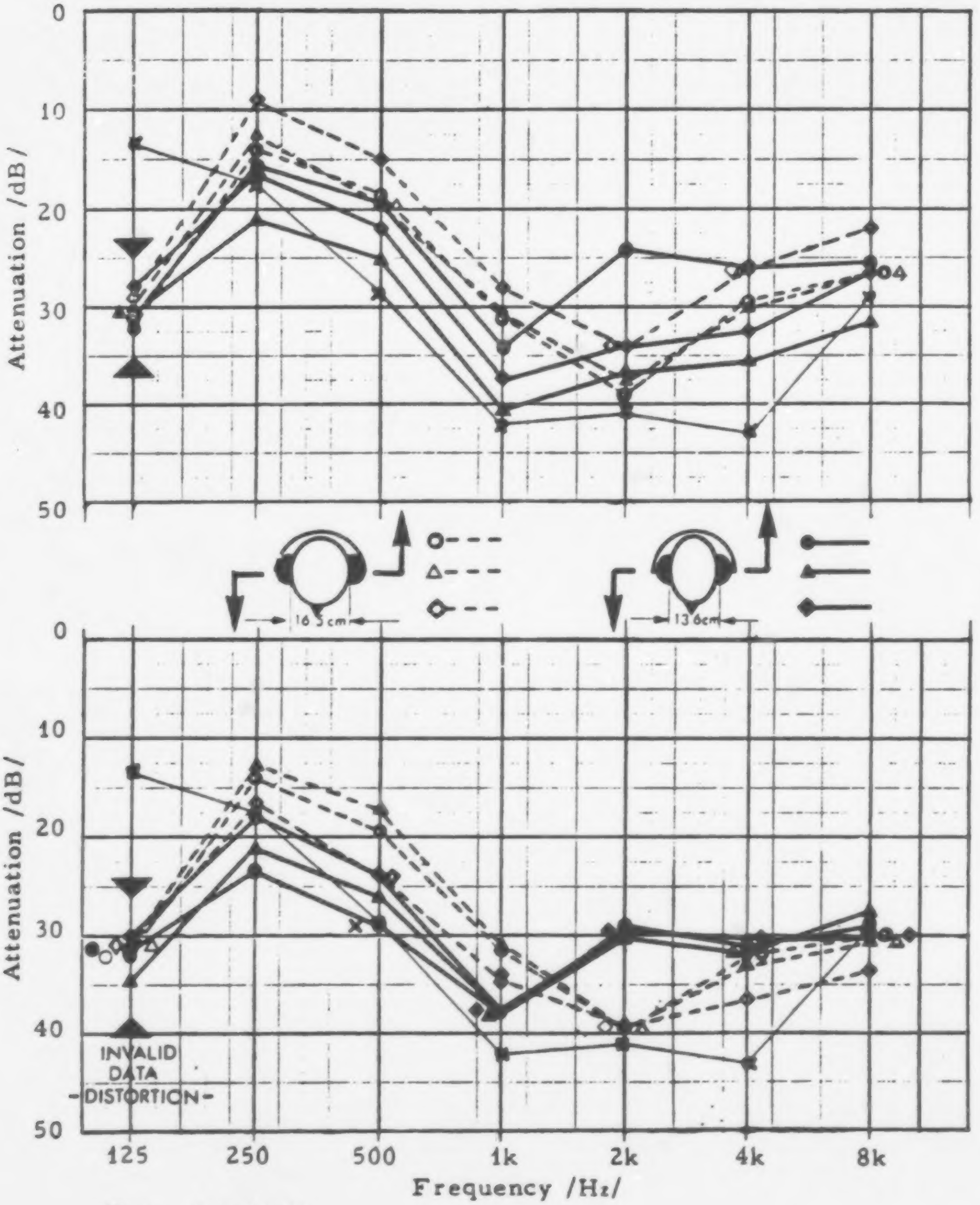
Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
✱ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 4 Model NO NOISE Helmet Muffs, Hellberg, Sweden



Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
■ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 5 Model NO NOISE, Hellberg, Sweden



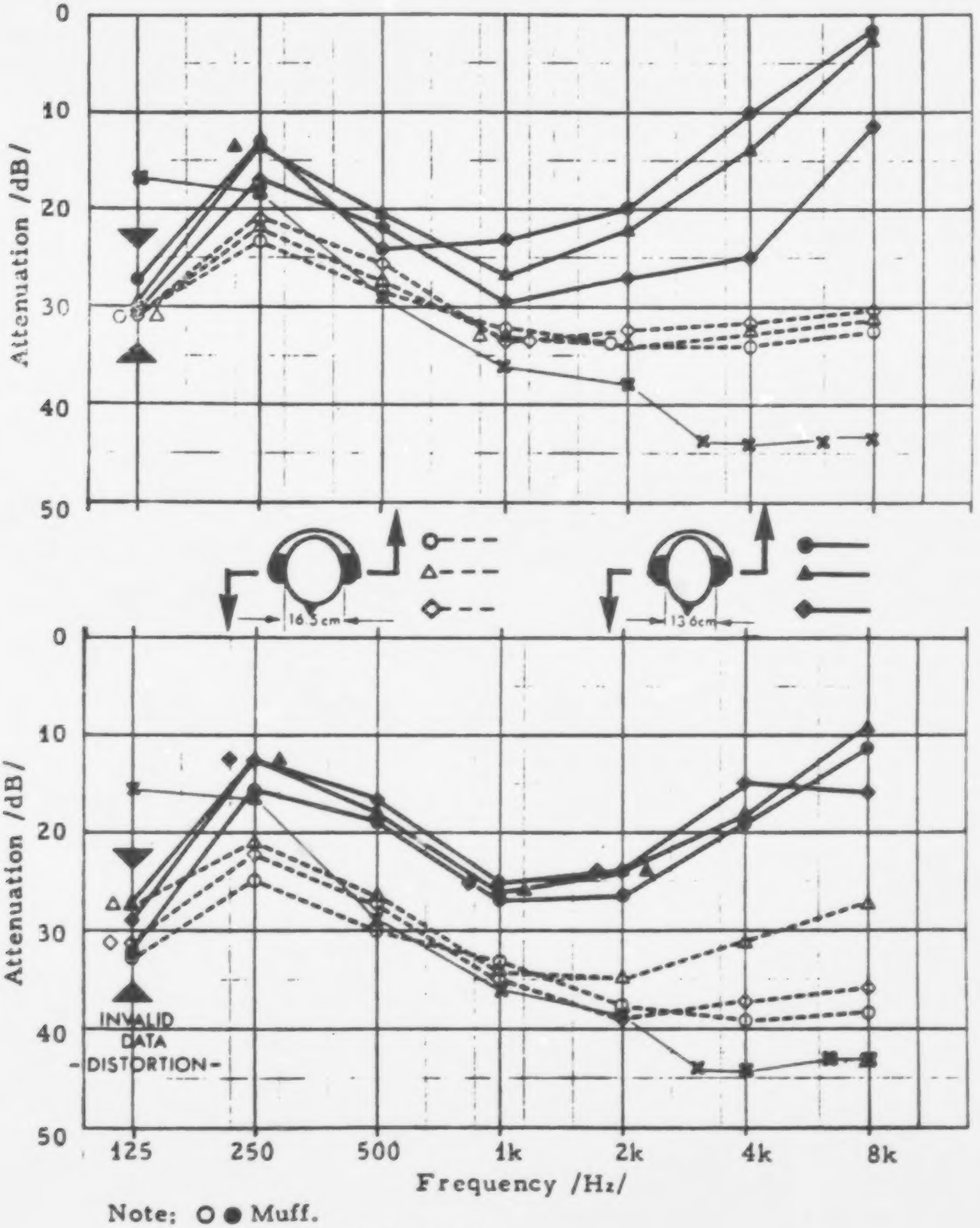
Note: ○ ● Muff.

△ ▲ Muff and Glasses.

◇ ◆ Muff, Glasses and Adapter.

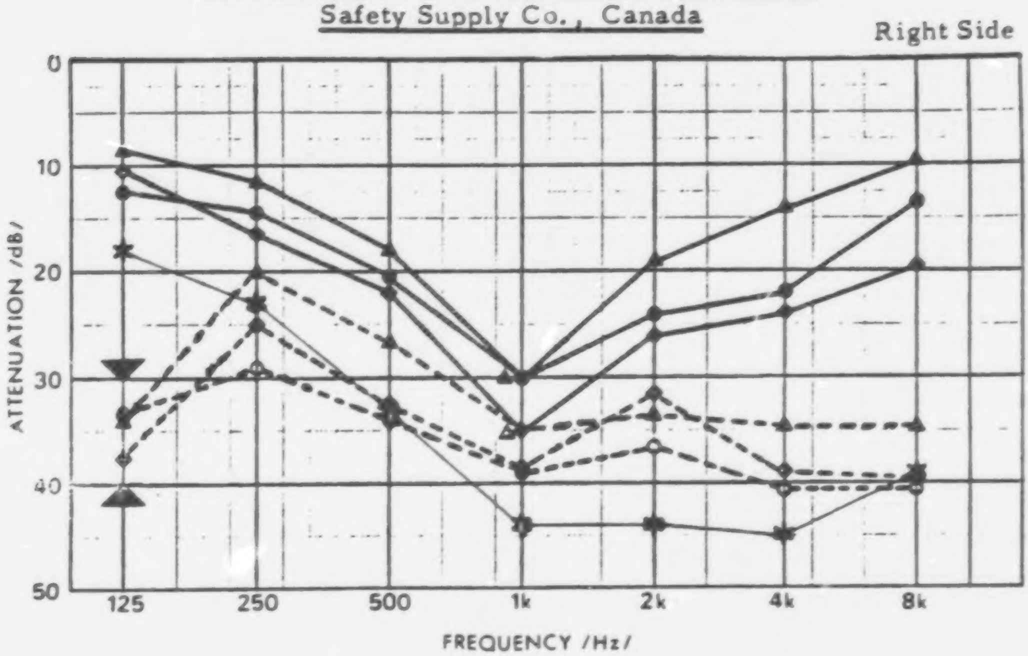
✕ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

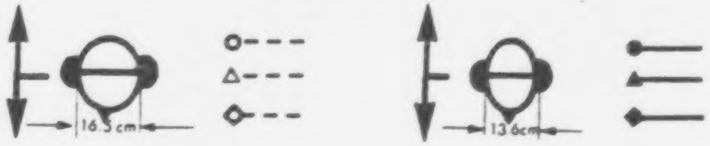
No. 6 Model Mark IV, MSA, U.S.A.

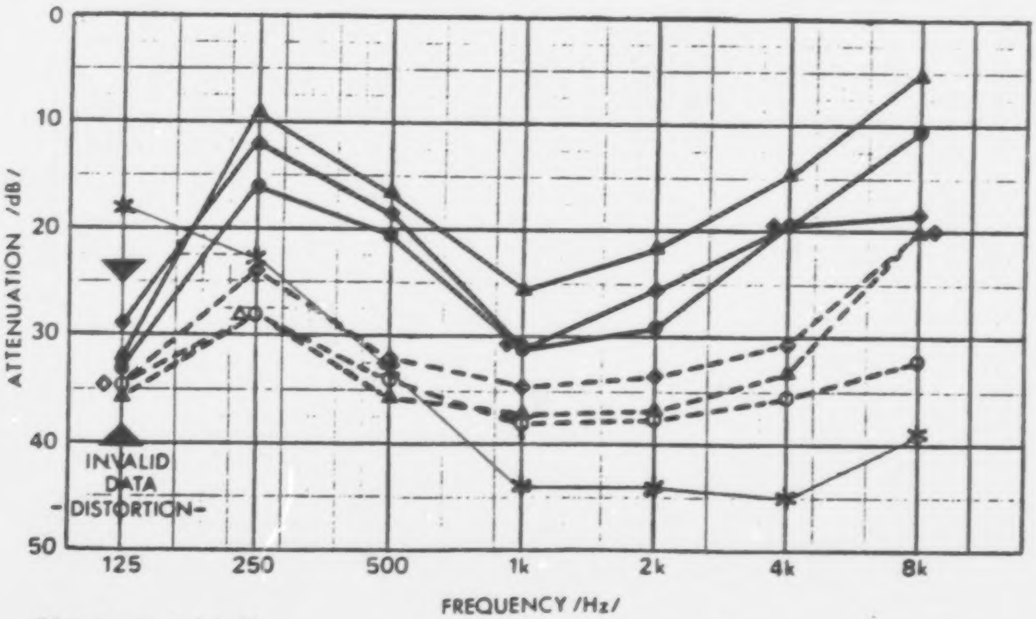


Note; ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 7 Model 290-S Safe-T-Earmuff (Gray)
Safety Supply Co., Canada





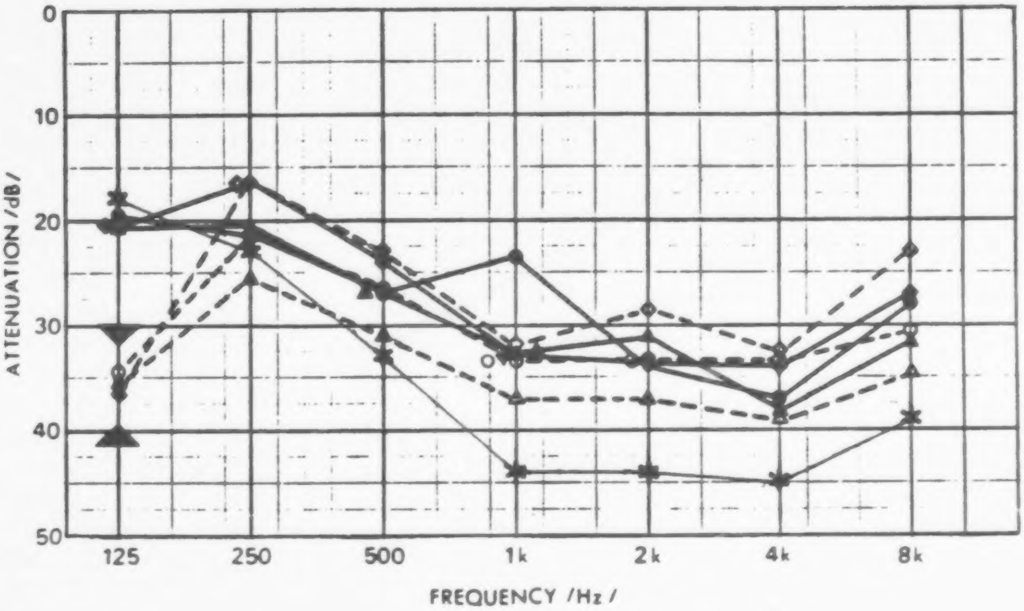


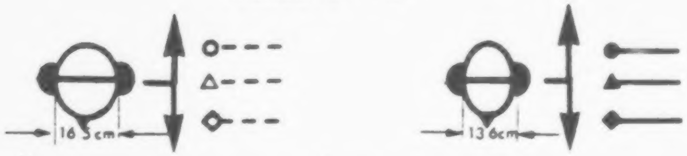
Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
✱ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

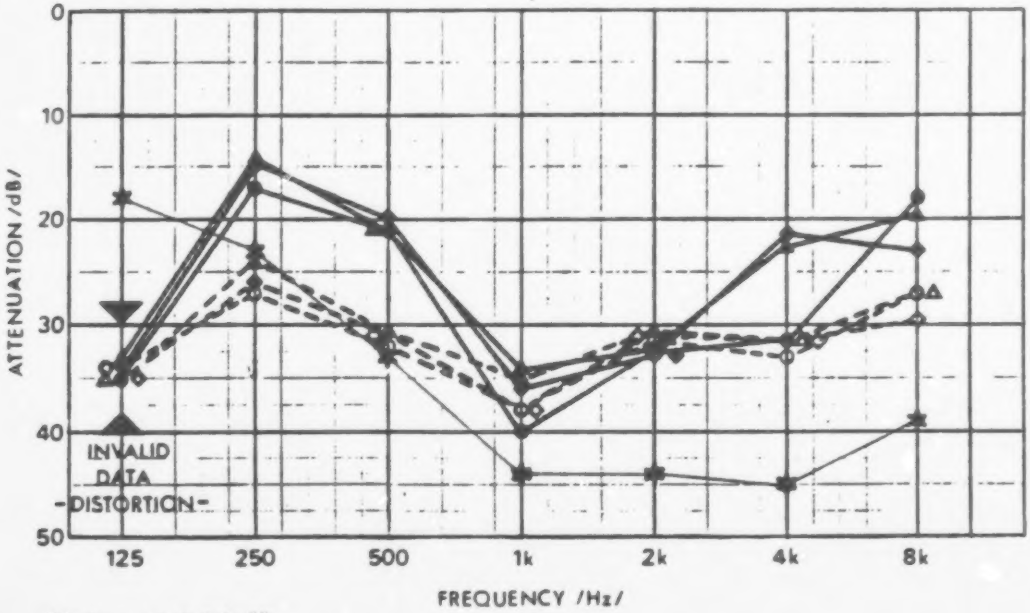
No. 7 Model 290-S Safe-T-Earmuff (Gray)

Safety Supply Co., Canada

Left Side







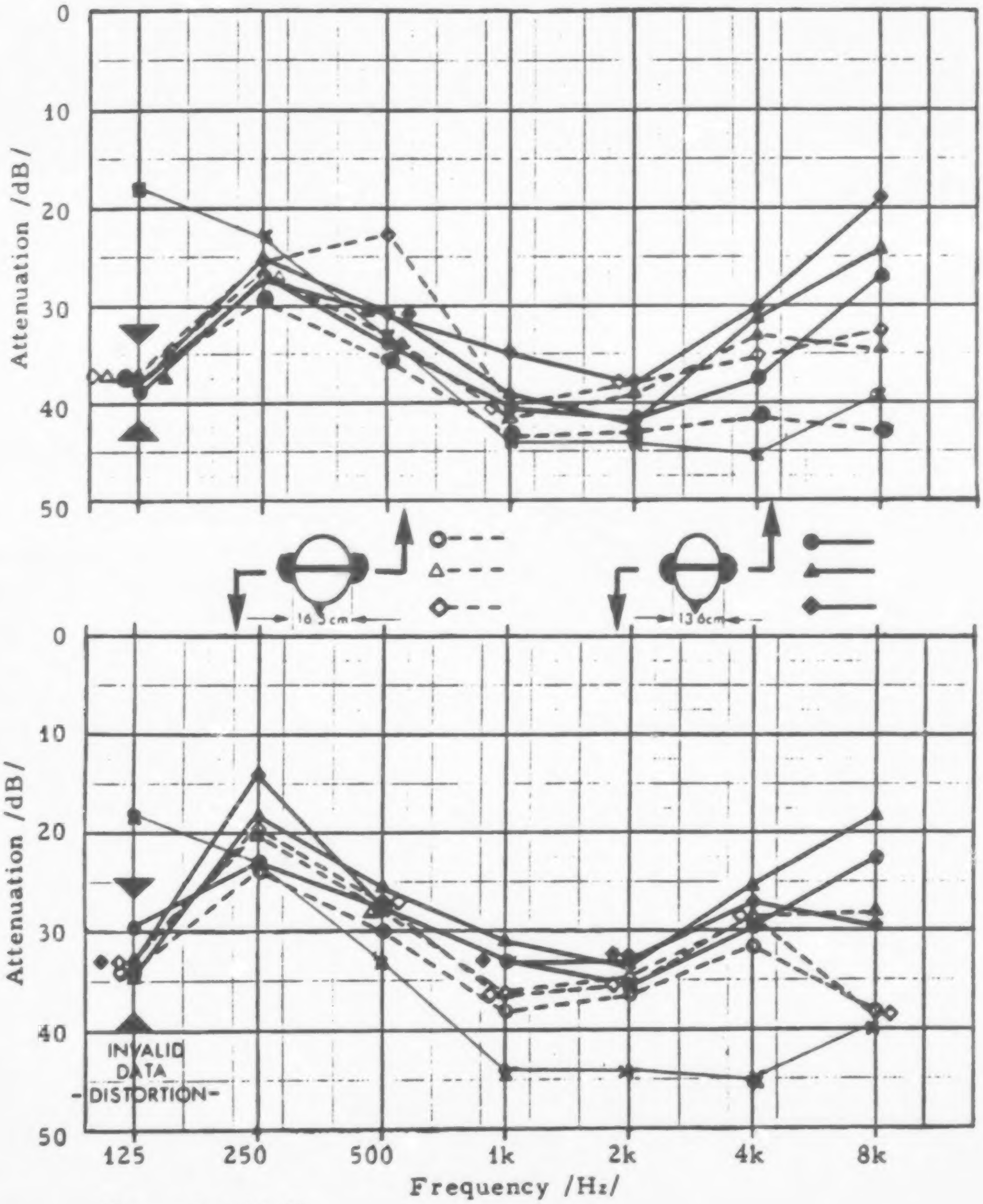
Note: ○ ● Muff.

△ ▲ Muff and Glasses.

◇ ◆ Muff, Glasses and Adapter.

* Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 8 Model 290-S Safe-T-Earmuff (yellow)
Safety Supply Co., Canada



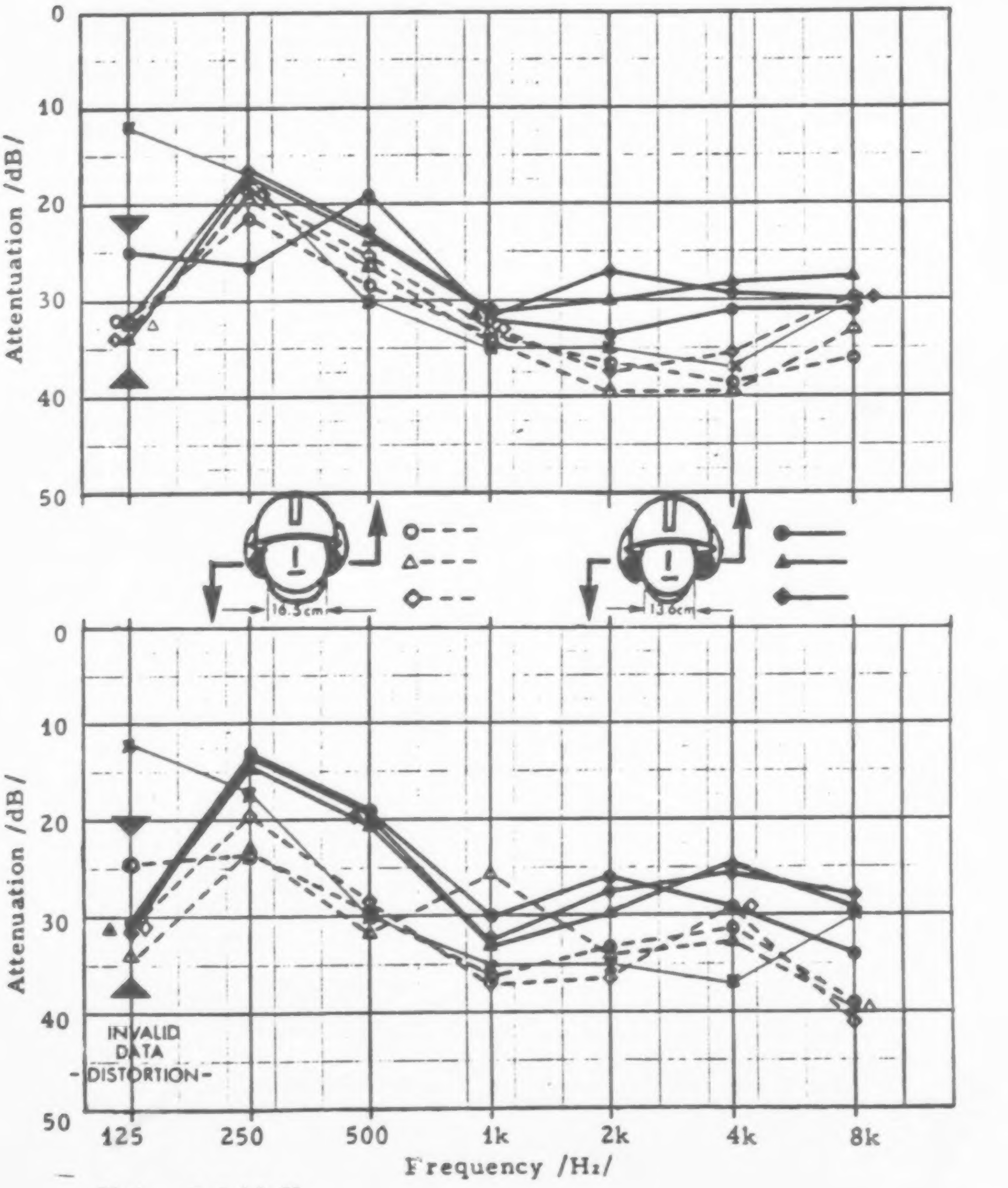
Note: ○ ● Muff.

△ ▲ Muff and Glasses.

◇ ◆ Muff, Glasses and Adapter.

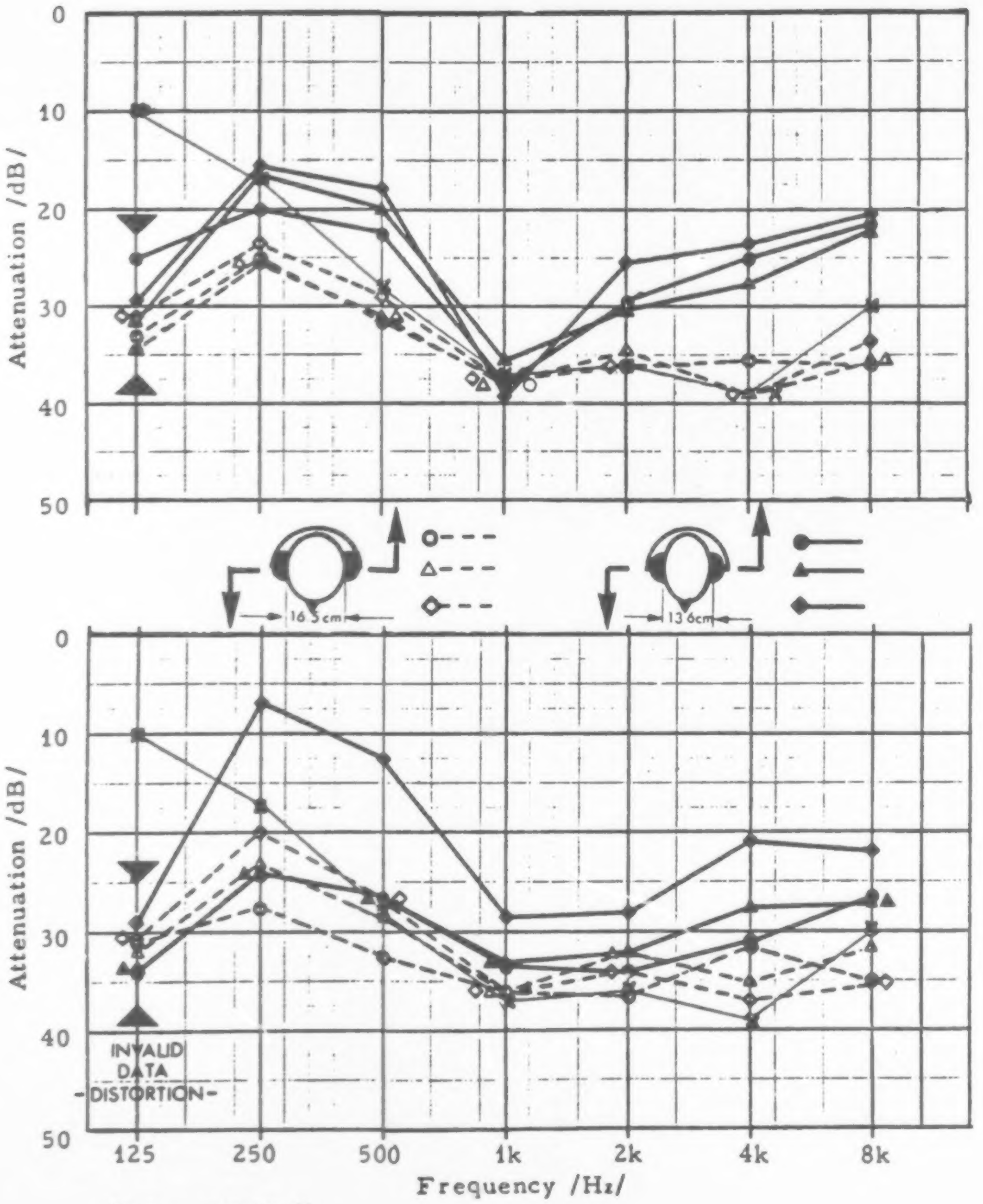
■ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 9 Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.



Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
✖ Attenuation characteristic measured in accordance with American National Standard Specification Z.24. 22-1957.

No. 10 Model E-805 Straightaway, D. Clark, U.S.A.



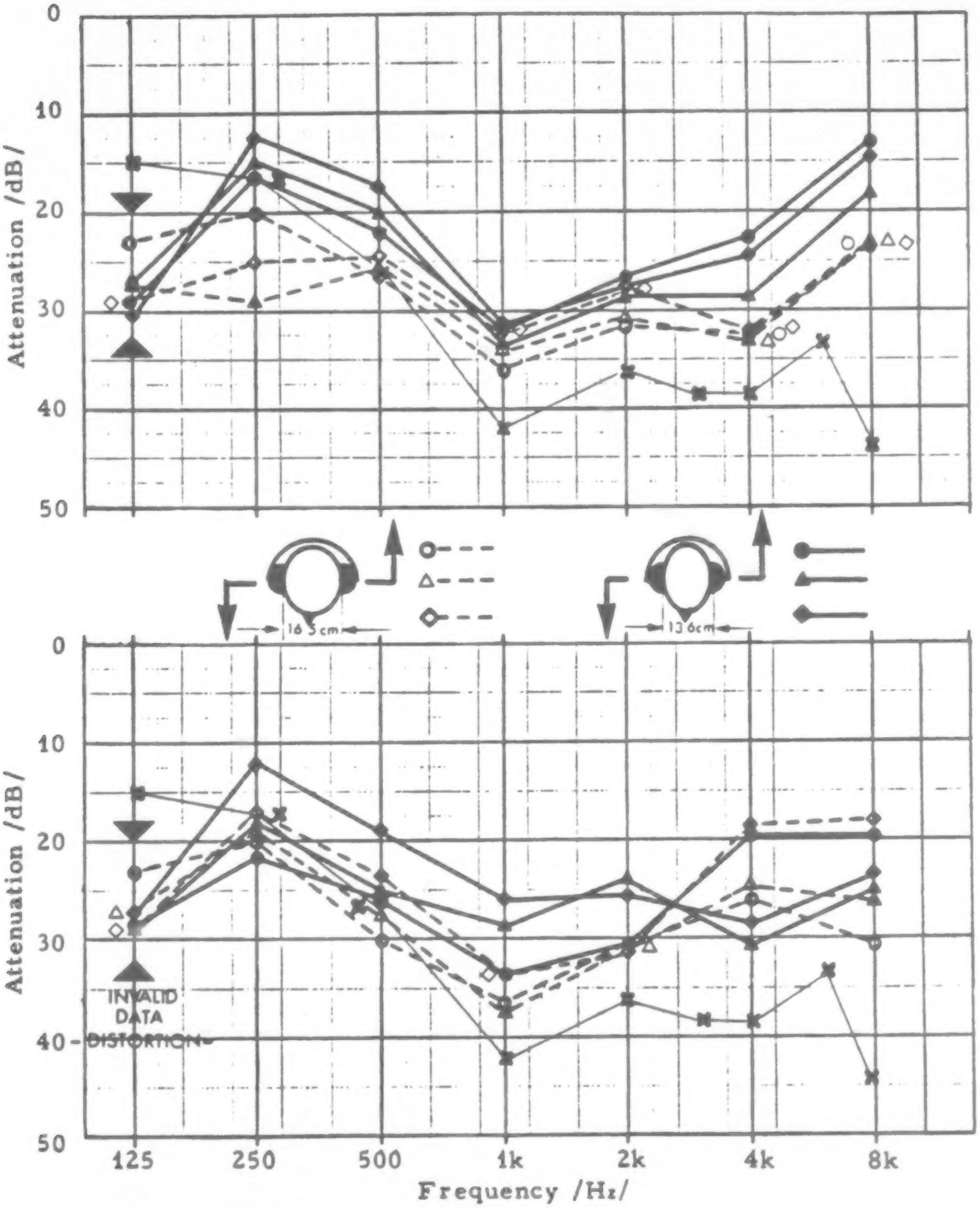
Note: ○ ● Muff.

△ ▲ Muff and Glasses.

◇ ◆ Muff, Glasses and Adapter.

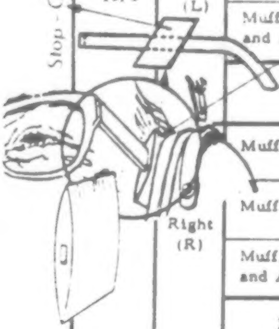
■ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

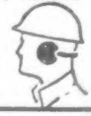
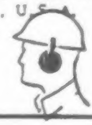
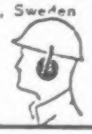
No. 11 Sound Barrier EM 152, Willson, U.S.A.



Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
■ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

Attenuation Reduction Data When the Neck is in Normal Position
(Subject used Glasses and Adaptors)

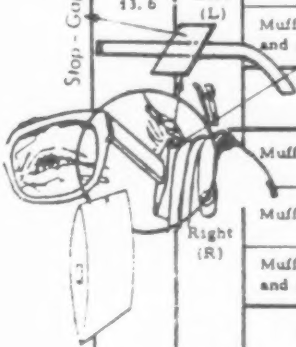


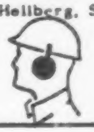
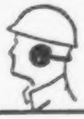
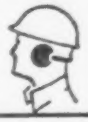
D (cm)	Hemisphere	No.	1		2		3	
		Ear Muff	Model 1675, Amer. Optical, U.S.A. 		Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A.  ①		Helmet Muffs -(HF), Bilsom, Sweden  ②	
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)	
			Meas.	Est'd*	Meas.	Est'd	Meas.	Est'd
13.6	Left (L)	Muff	28.5	27.5	30.5	29	37	35
		Muff and Glasses	23.5	25	26.5	27.5	33	33
		Muff, Glasses and Adapter	18.5	18.5	24	25	32	30
		Σ/3	23.5	23.7	27	27.2	34	32.7
	Right (R)	Muff	29	28	32	31	32	30
		Muff and Glasses	28	28	25.5	25	28	28
		Muff, Glasses and Adapter	26	26	21	21	26	26.5
		Σ/3	27.7	27.3	26.2	25.7	28.7	28.2
	$\frac{L+R}{2}$	$\frac{\Sigma/3+\Sigma/3}{2}$	25.6	25.5	26.6	26.5	31.4	30.5
			Clamping Force 580 (gwt)		Clamping Force 1005 (gwt)		Clamping Force 730 (gwt)	
16.5	Left (L)	Muff	34.5	34	37	37	31	30
		Muff and Glasses	33.5	33	35	35	33.5	32.5
		Muff, Glasses and Adapter	32.5	32	29.5	29.5	33	31
		Σ/3	33.5	33	33.8	33.8	32.5	31.2
	Right (R)	Muff	28.5	28	32	31	28.5	28
		Muff and Glasses	29	24.5	34	34	30	30
		Muff, Glasses and Adapter	19.5	19	30	30	30.5	31.5
		Σ/3	25.7	23.8	32	31.7	29.7	29.8
	$\frac{L+R}{2}$	$\frac{\Sigma/3+\Sigma/3}{2}$	29.6	28.4	32.9	32.8	31.1	30.5
			Clamping Force 780 (gwt)		Clamping Force 1355 (gwt)		Clamping Force 930 (gwt)	

NOTE:
① Tested while mounted on helmet; B x 18A Safety Cap, CSA Standard Z 94.1
② Tested while mounted on helmet; Class C, CSA Standard Z 94.1

* Total noise estimated from the octave-band noise levels given in the Appendix A-2

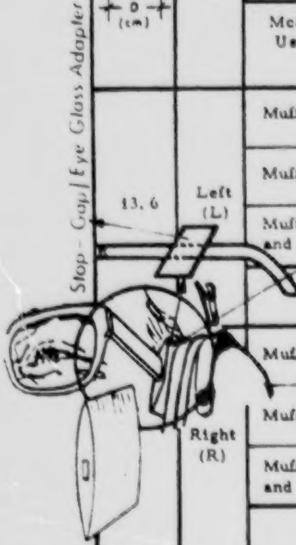
Cont.

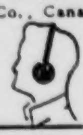
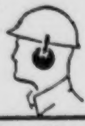


 D (cm)	Hemisphere	No.	4		5		6	
		Ear Muff	Model NO NOISE Helmet Muffs, Hellberg, Sweden  ③		Model NO NOISE, Hellberg, Sweden 		Model Mark IV, MSA, U.S.A. 	
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)	
			Meas.	Est'd	Meas.	Est'd	Meas.	Est'd
13.6	Left (L)	Muff	31.5	31.5	24.5	25.5	17	14
		Muff and Glasses	30.5	29.5	36	36	14	14.5
		Muff, Glasses and Adapter	32.5	33.5	31.5	33	26	25
		Σ/3	31.5	31.5	30.7	31.5	19	17.8
	Right (R)	Muff	28.5	29	31	30	21.5	21
		Muff and Glasses	26	25.5	30	31	20.5	20.5
		Muff, Glasses and Adapter	23.5	24.5	31	30.5	21	20
		Σ/3	26	26.3	30.7	30.5	21	20.5
	(L + R)/2	(Σ/3 + Σ/3)/2	28.8	28.9	30.7	31	20	19.2
			Clamping Force 980 (gwt)		Clamping Force 1980 (gwt)		Clamping Force 1180 (gwt)	
16.5	Left (L)	Muff	34	33.5	32.5	32.5	35	33.5
		Muff and Glasses	32	31	32.5	32.5	33	33.5
		Muff, Glasses and Adapter	29	28.5	29.5	29	32.5	37
		Σ/3	31.7	31	31.5	31.3	33.5	33
	Right (R)	Muff	32.5	33	34	33.5	36.5	36.5
		Muff and Glasses	30.5	30	34	33.5	33.5	33.5
		Muff, Glasses and Adapter	29.5	29.5	31	32.5	37.5	37
		Σ/3	30.8	30.8	33	33.2	35.8	35.7
	(L + R)/2	(Σ/3 + Σ/3)/2	31.3	30.9	32.3	32.3	34.7	34.4
			Clamping Force 1230 (gwt)		Clamping Force 2580 (gwt)		Clamping Force 1580 (gwt)	

NOTE ③ Tested while mounted on helmet; Class C, CSA Standard Z 94.1

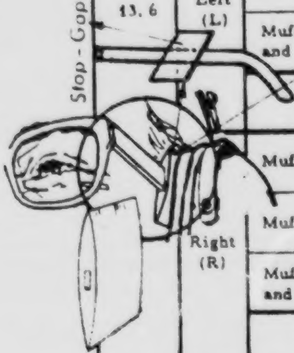
Cont.



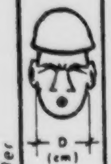
D (cm)	Hemisphere	No.	7**		8		9	
		Ear Muff	Model 290-S Safe-T-Ear-Muff (gray), Safety Supply Co., Canada		Model 290-S Safe-T-Ear-Muff (yellow) Safety Supply Co., Canada 		Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.  ④	
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)	
			Meas.	Est'd	Meas.	Est'd	Meas.	Est'd
13.6	Left (L)	Muff	-	30.7	32.5	35.5	31.5	31
		Muff and Glasses	-	30.4	30	28.5	29.5	29
		Muff, Glasses and Adapter	-	30.5	31.5	31	28.5	28
		Σ/3	-	30.5	31.3	31.7	29.8	29.3
	Right (R)	Muff	-	23.5	42	42.5	27	27
		Muff and Glasses	-	17.4	36.5	35.5	28.5	28
		Muff, Glasses and Adapter	-	24.8	37.5	37	27	27
		Σ/3	-	21.9	38.7	38.3	27.5	27.3
	(L + R)/2	(Σ/3 + Σ/3)/2	-	26.2	35	35	28.7	28.3
			Clamping Force 1230 (gwt)		Clamping Force 1130 (gwt)		Clamping Force 730 (gwt)	
16.5	Left (L)	Muff	-	32.6	38.5	38.5	36	35
		Muff and Glasses	-	34.1	34.5	35	37.5	38
		Muff, Glasses and Adapter	-	30.3	32.5	32.5	35.5	35
		Σ/3	-	32.3	35.2	35.3	36.3	36
	Right (R)	Muff	-	37.3	35	35	33	33
		Muff and Glasses	-	34.4	33	32.5	33.5	34
		Muff, Glasses and Adapter	-	32.7	34	33.5	34	33
		Σ/3	-	34.8	34	33.7	33.5	33.3
	(L + R)/2	(Σ/3 + Σ/3)/2	-	33.6	34.6	34.5	34.9	34.7
			Clamping Force 1480 (gwt)		Clamping Force 1330 (gwt)		Clamping Force 1005 (gwt)	

NOTE: ** Measurements are not enclosed in Arithmetic Mean of all Ear Muffs.
④ Tested while mounted on helmet; Class C, CSA Standard Z 94.1

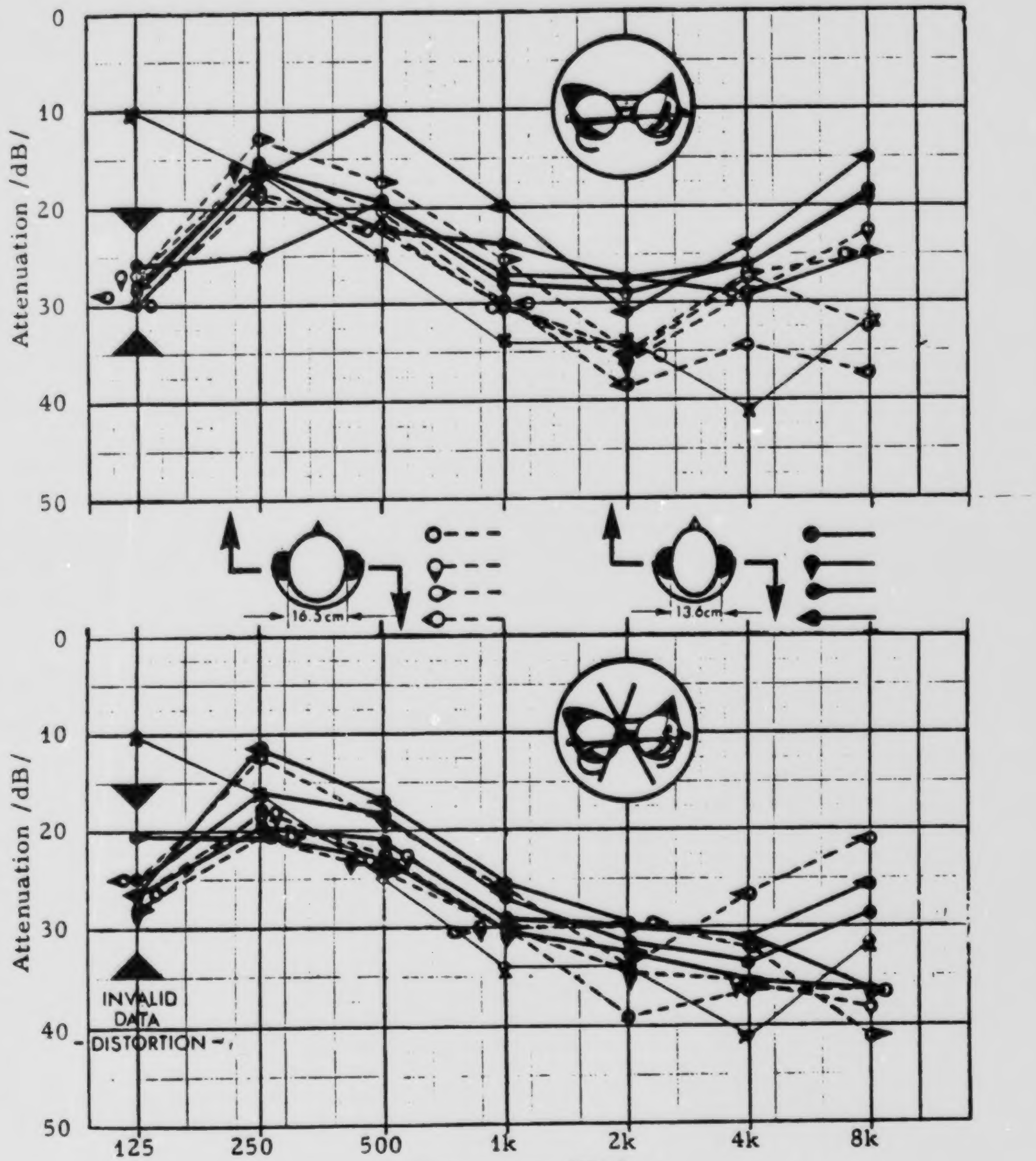
Cont.



Stop - Gap / Eye Glass Adapter

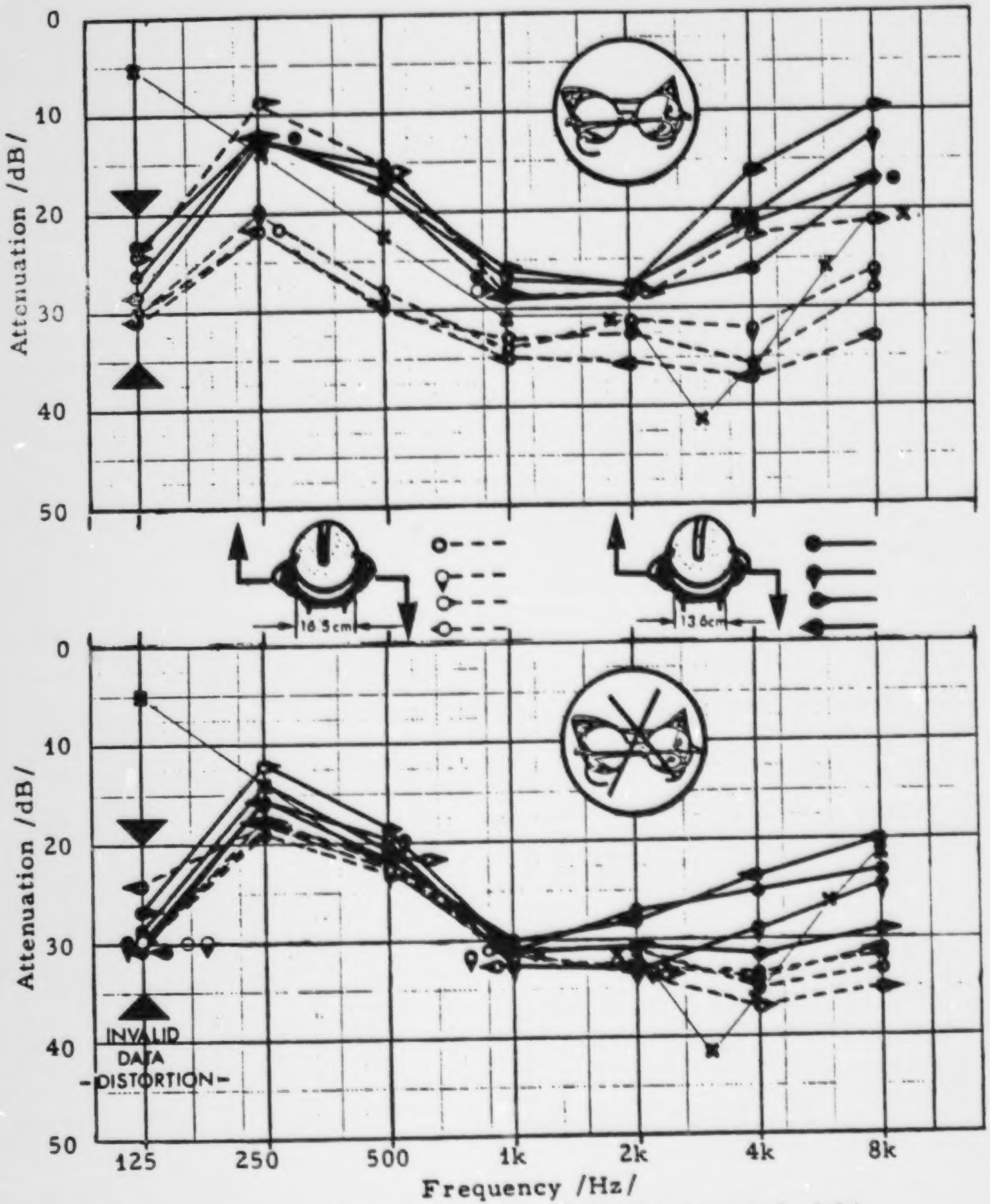
D (cm) 	Hemisphere	No.	10		11		Arithmetic Mean of all Ear Muffs			
		Ear Muff	Model E-805 Straightaway D. Clark, U.S.A.		Sound Barrier EM 152 Willson, U.S.A.					
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Mean Attenuation (dBA)			
			Meas.	Est'd	Meas.	Est'd	Meas.	St. dev	Est'd	St. dev
13.6	Left (L)	Muff	29.5	31	23	24	28.55	5.67	28.4	6.27
		Muff and Glasses	29	29	28	28	28	5.97	28	5.63
		Muff, Glasses and Adapter	31	26	24.5	24.5	28	4.62	27.45	4.59
		Σ/3	29.8	28.7	25.2	25.5	28.18	4.51	27.96	4.62
	Right (R)	Muff	33	32	25	29.5	30.1	5.49	30	5.34
		Muff and Glasses	31.5	30	25.5	28.5	28	4.02	28	3.96
		Muff, Glasses and Adapter	29	25	26.5	23.5	26.85	4.9	26.1	4.86
		Σ/3	31.2	29	25.7	27.2	28.34	4.63	28.03	4.46
	$\frac{L+R}{2}$	$\frac{\Sigma/3+\Sigma/3}{2}$	30.5	28.9	25.5	26.4	28.26	3.03	28	3.01
			Clamping Force 1330 (gwt)		Clamping Force 980 (gwt)					
16.5	Left (L)	Muff	33	36	31.5	25	34.3	2.41	33.5	3.82
		Muff and Glasses	31.5	36	31	25.5	33.4	1.91	33.2	3.27
		Muff, Glasses and Adapter	30	36	29.5	26	31.35	2.15	31.15	3.03
		Σ/3	31.5	36	30.7	25.5	33.02	1.78	32.61	3.14
	Right (R)	Muff	34	35.5	31	32	32.5	2.61	32.55	2.9
		Muff and Glasses	36	33	29	31	32.25	2.43	31.6	2.93
		Muff, Glasses and Adapter	36	34.5	23.5	29.5	30.55	5.53	31	4.83
		Σ/3	35.3	34.3	27.8	30.8	31.76	3.27	31.77	3.32
	$\frac{L+R}{2}$	$\frac{\Sigma/3+\Sigma/3}{2}$	33.4	35.2	29.3	28.2	32.39	2.28	32.16	2.54
			Clamping Force 1930 (gwt)		Clamping Force 1280 (gwt)					

No. 1 Model 1675, Amer. Optical, U.S.A.



Note: ○ ● Head elevated ◑ ● Head turned right
⚲ ⚲ Head lowered ◐ ● Head turned left
✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 2 Model 1750 Cap Mounted Hearing Protector
Amer. Optical, U.S.A.

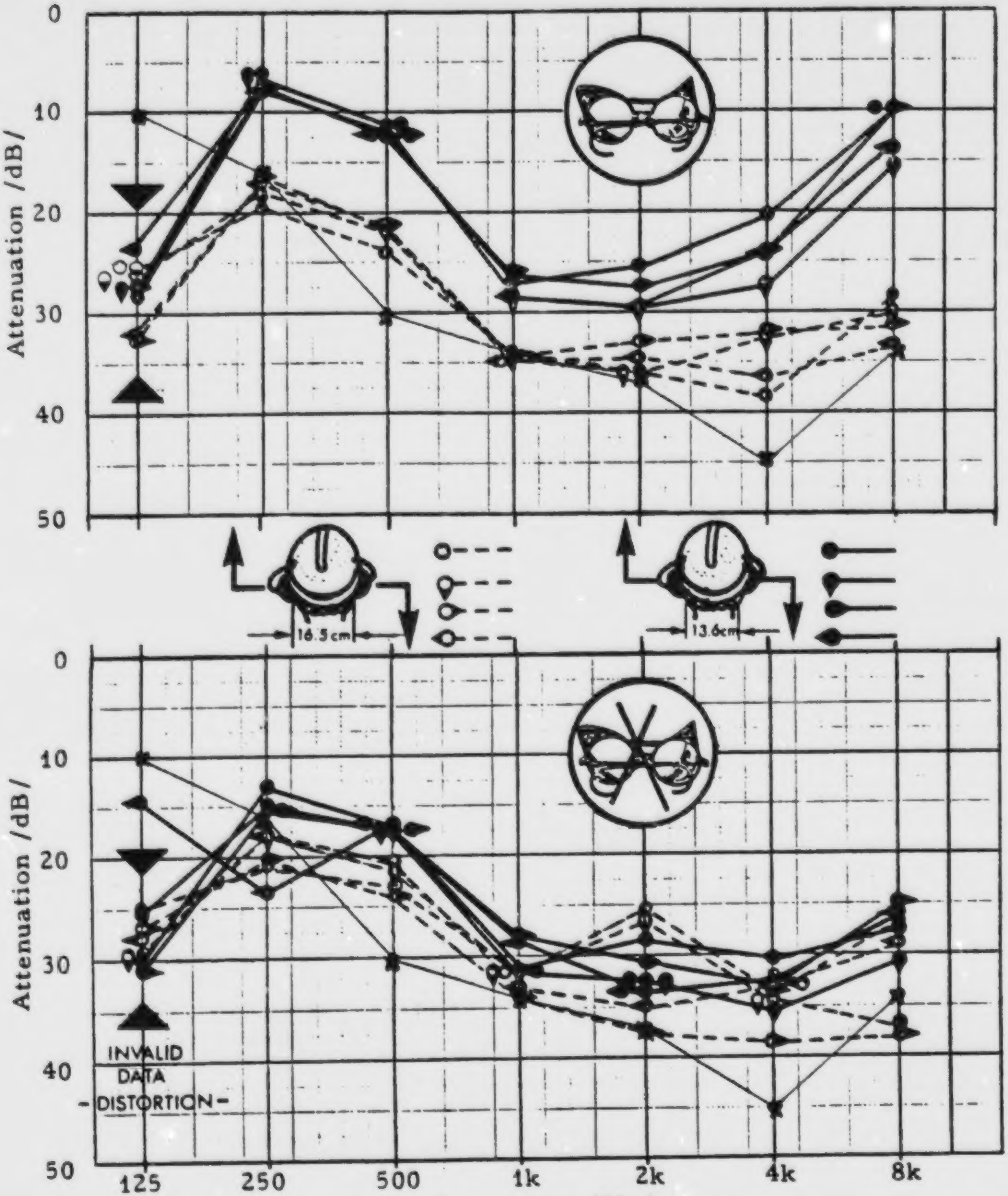


Note: ○ ● Head elevated ◑ ● Head turned right

♀ ♀ Head lowered ◐ ● Head turned left

✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24.22-1957.

No. 3 Helmet Muffs - (HF), Bilsom Sweden

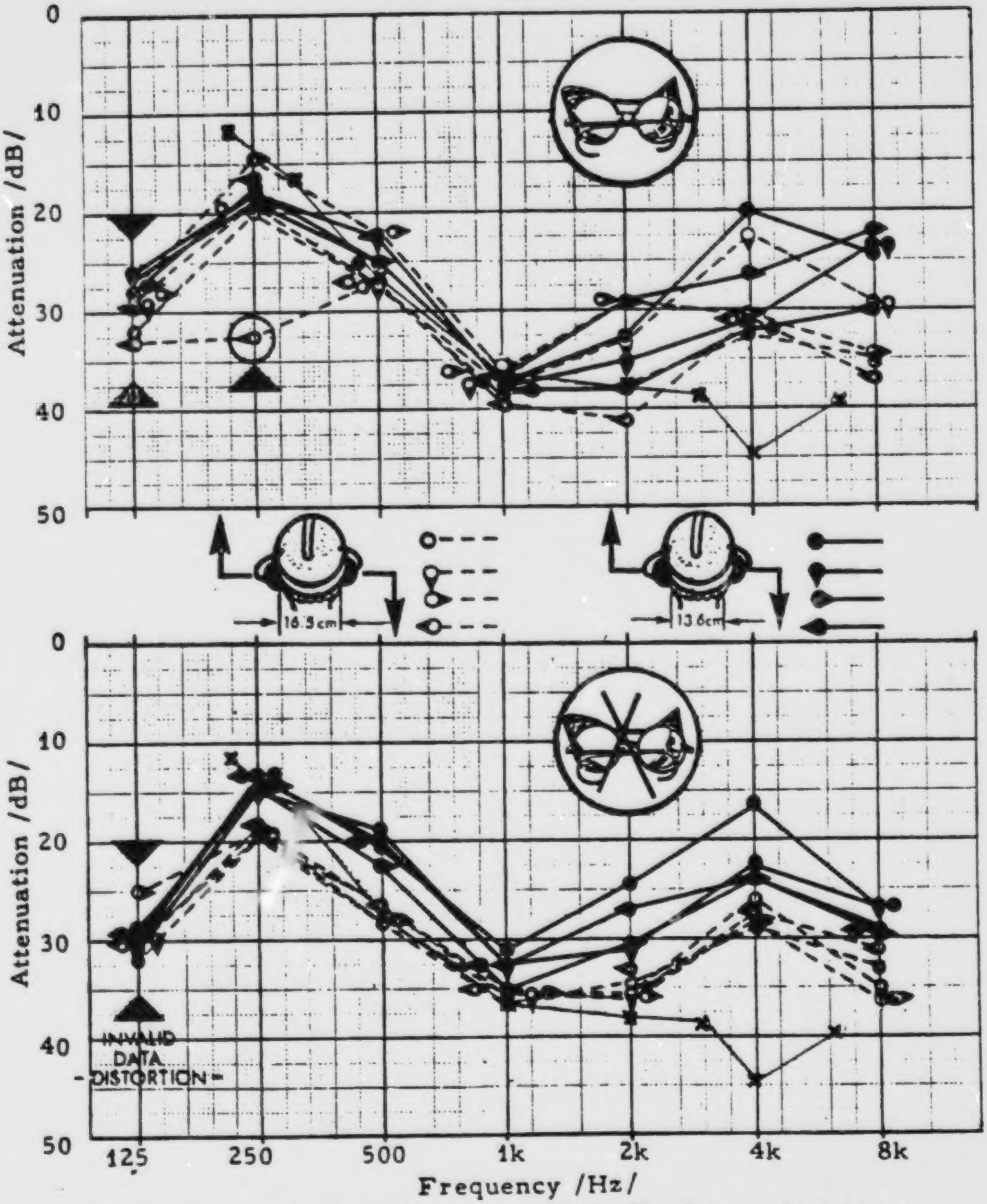


Note: ○ ● Head elevated ◐ ● Head turned right

⚲ ⚲ Head lowered ◑ ● Head turned left

★ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 4 Model NO NOISE Helmet Muffs, Hellberg, Sweden



Note: ○ ● Head elevated

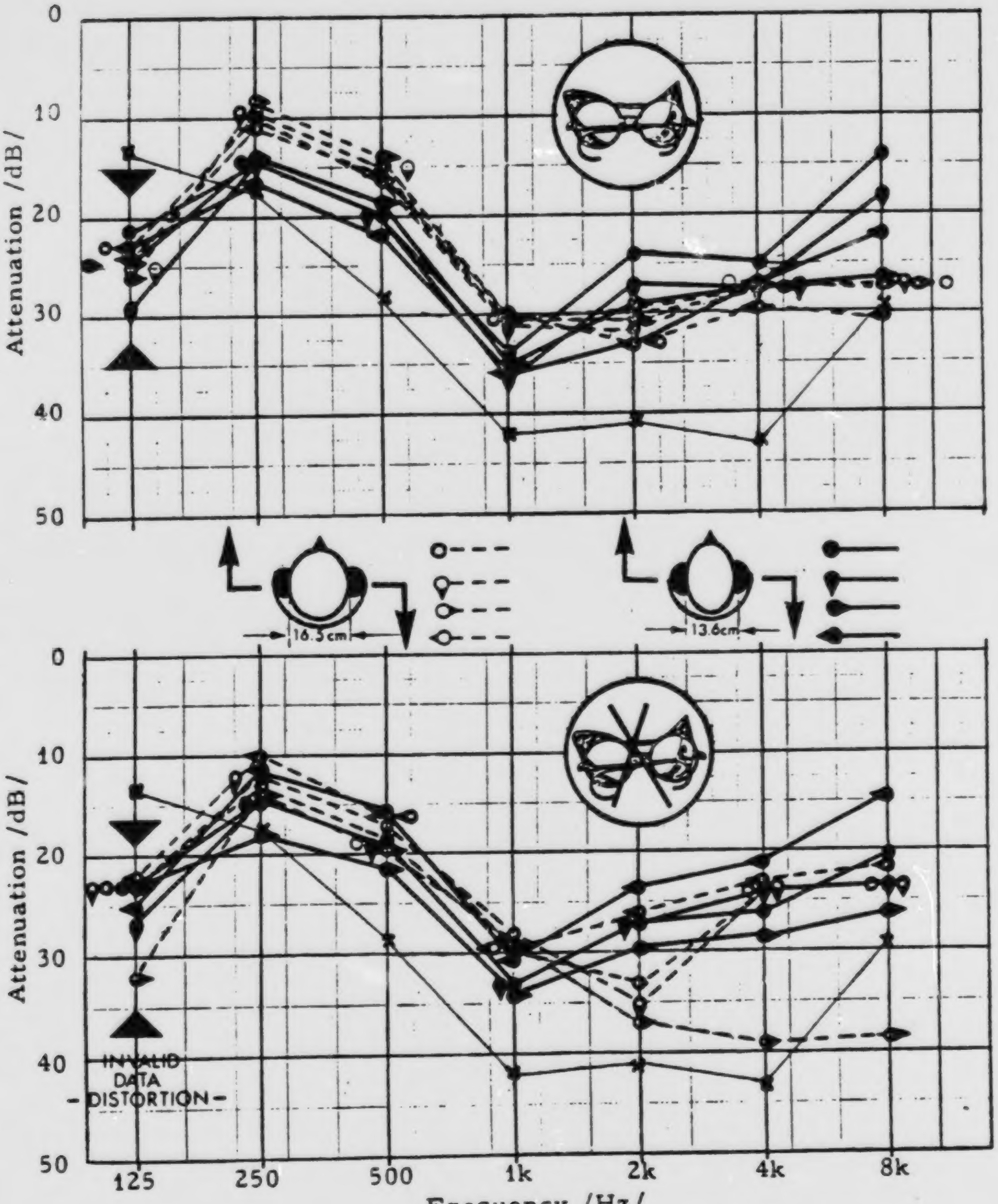
Head lowered

Head turned right

Head turned left

■ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 5 Model NO NOISE, Hellberg, Sweden



Note: ○ ● Head elevated

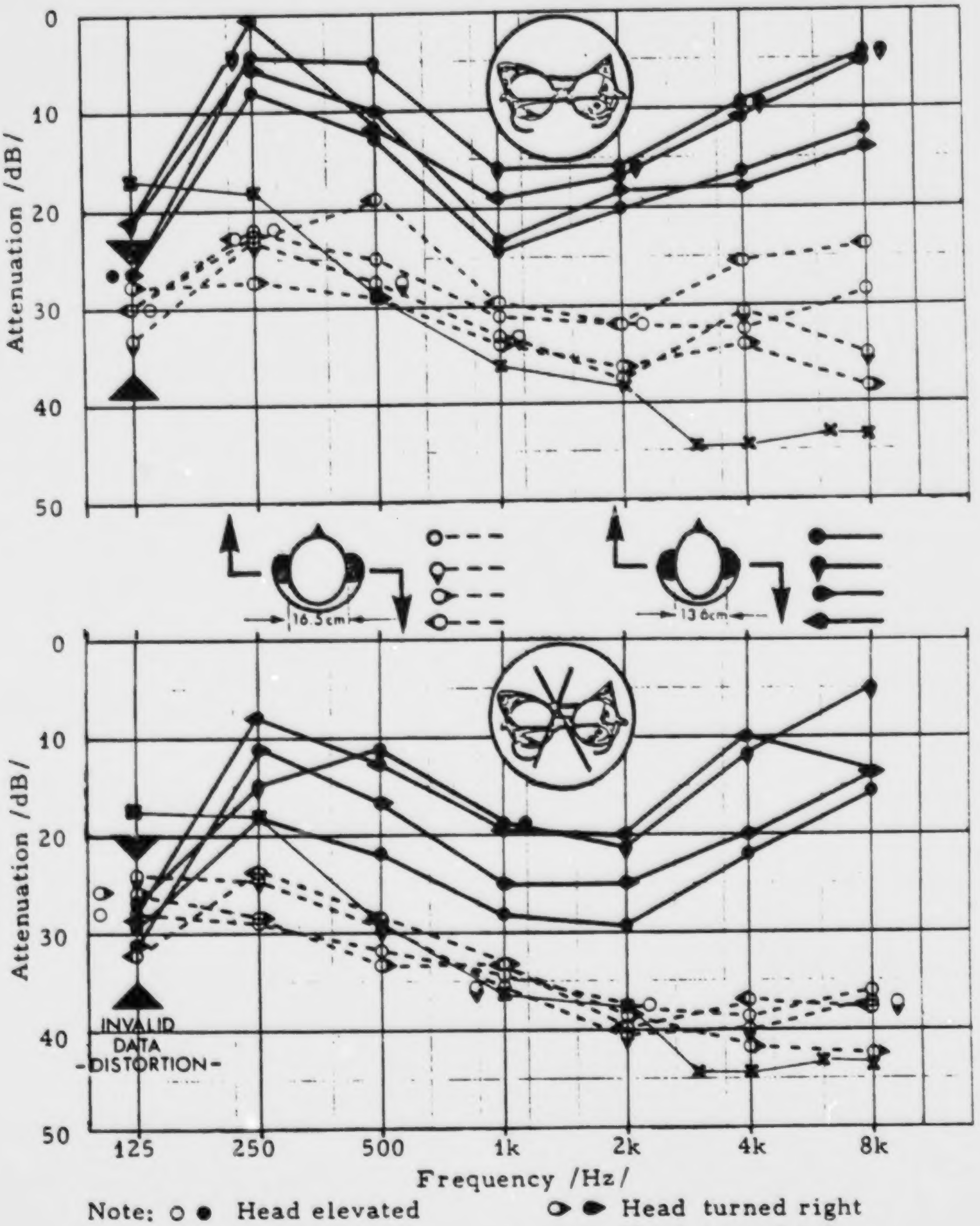
◓ ● Head lowered

◑ ● Head turned right

◐ ◀ Head turned left

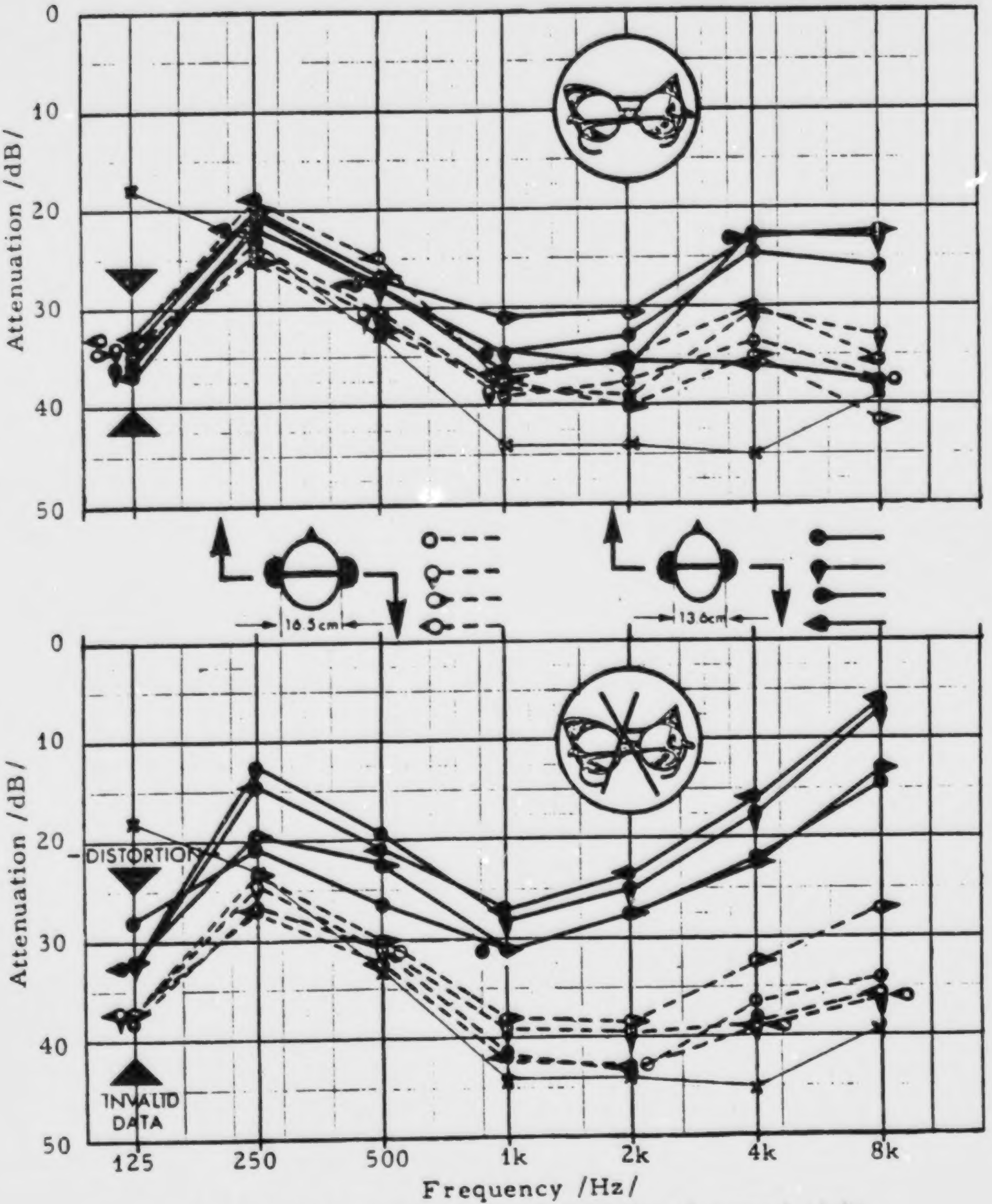
✱ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 6 Model Mark IV, MSA, U.S.A.



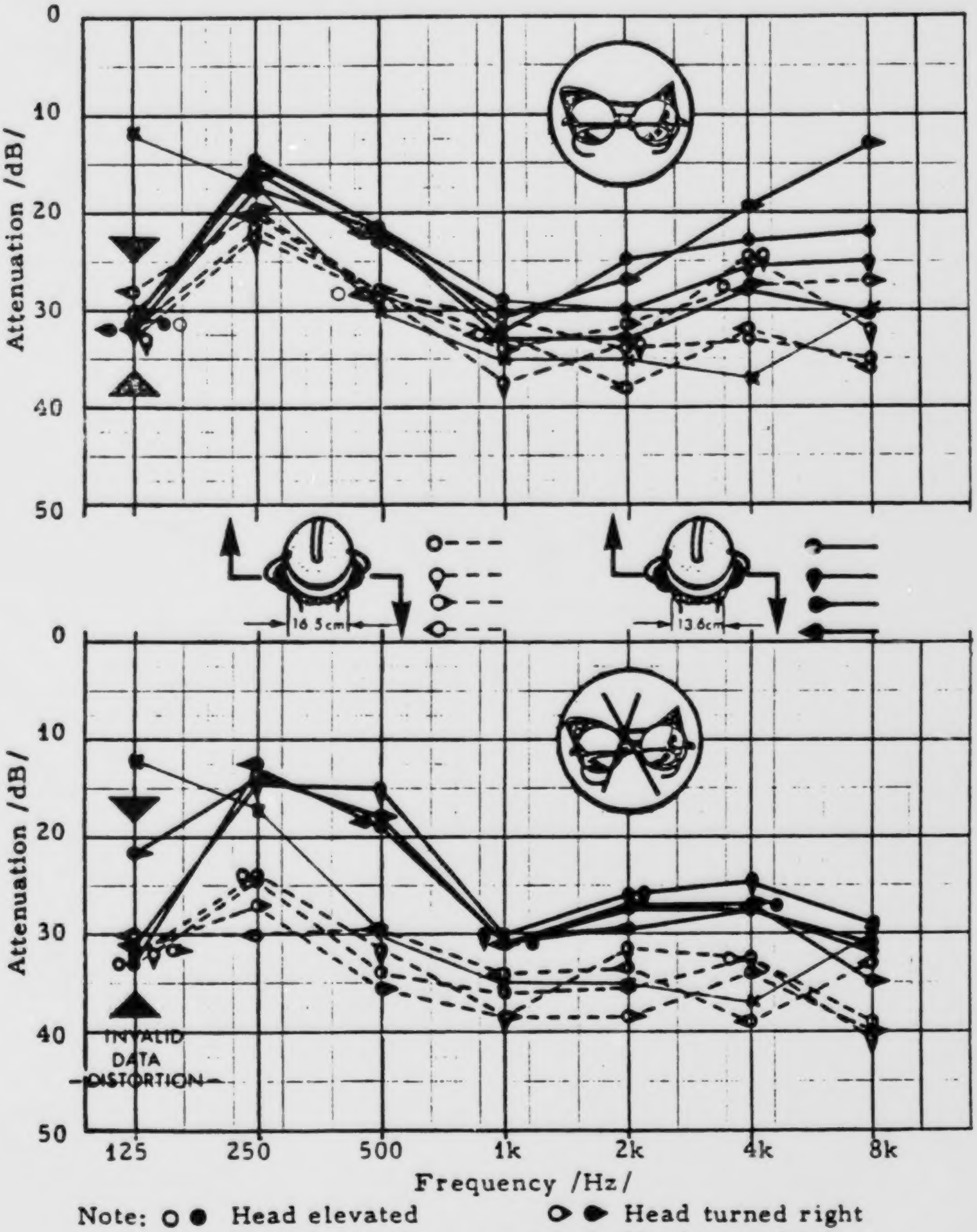
Note: ○ ● Head elevated
◐ ◑ Head turned right
Head lowered
◐ ◑ Head turned left
■ Attenuation characteristic measured in accordance with American National Standard Specification Z24.22-1957.

No. 8 Model 290-S Safe-T-Earmuff (yellow)
Safety Supply Co., Canada



Note: ○ ● Head elevated
◐ ◑ Head turned right
Head lowered
Head turned left
■ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 9 Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.

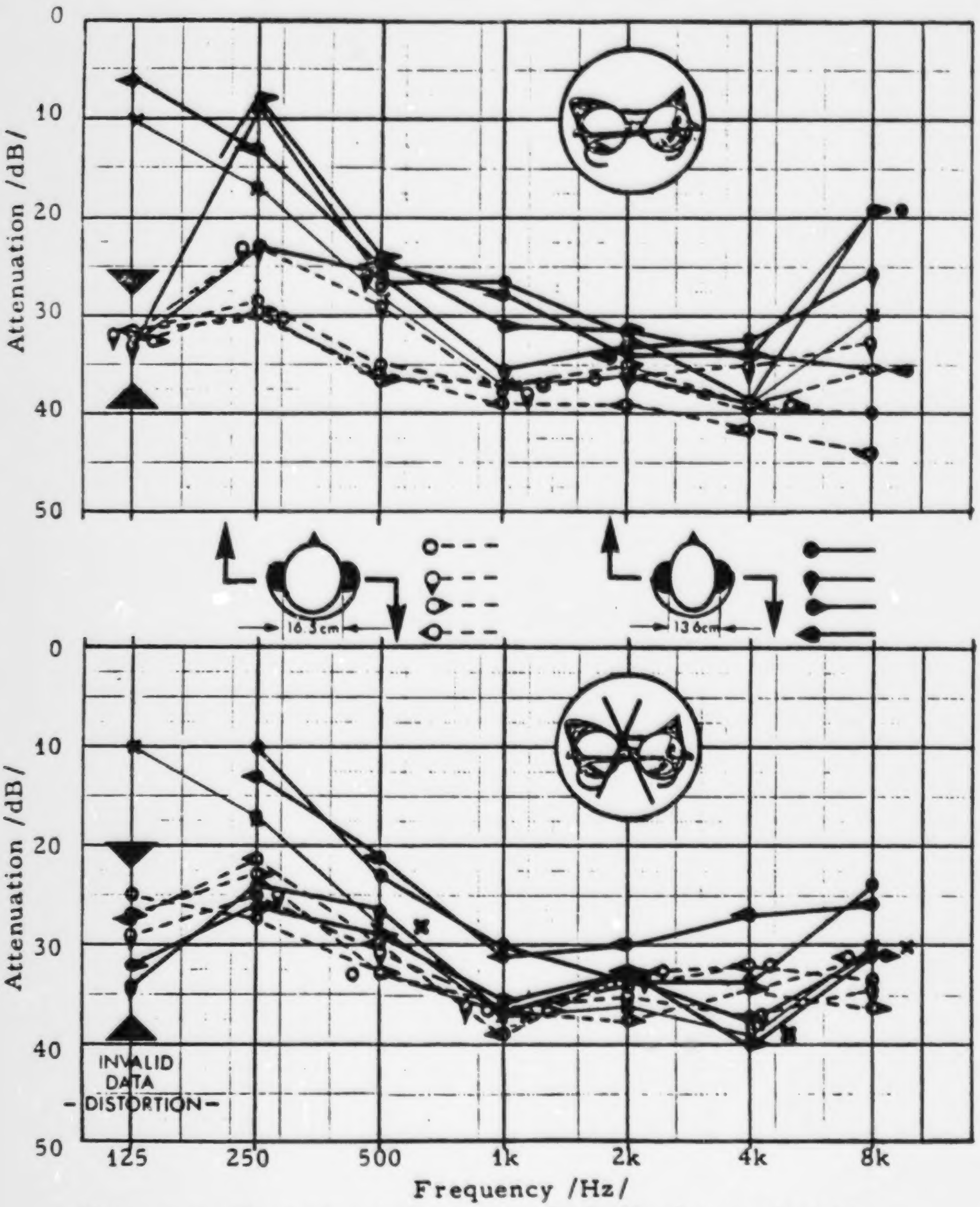


Note: ○ ● Head elevated ◑ ● Head turned right

⚲ ⚲ Head lowered ◐ ◀ Head turned left

× Attenuation characteristic measured in accordance with American National Standard Specification Z24.22-1957.

No. 10 Model E-805 Straightaway, D. Clark, U.S.A.

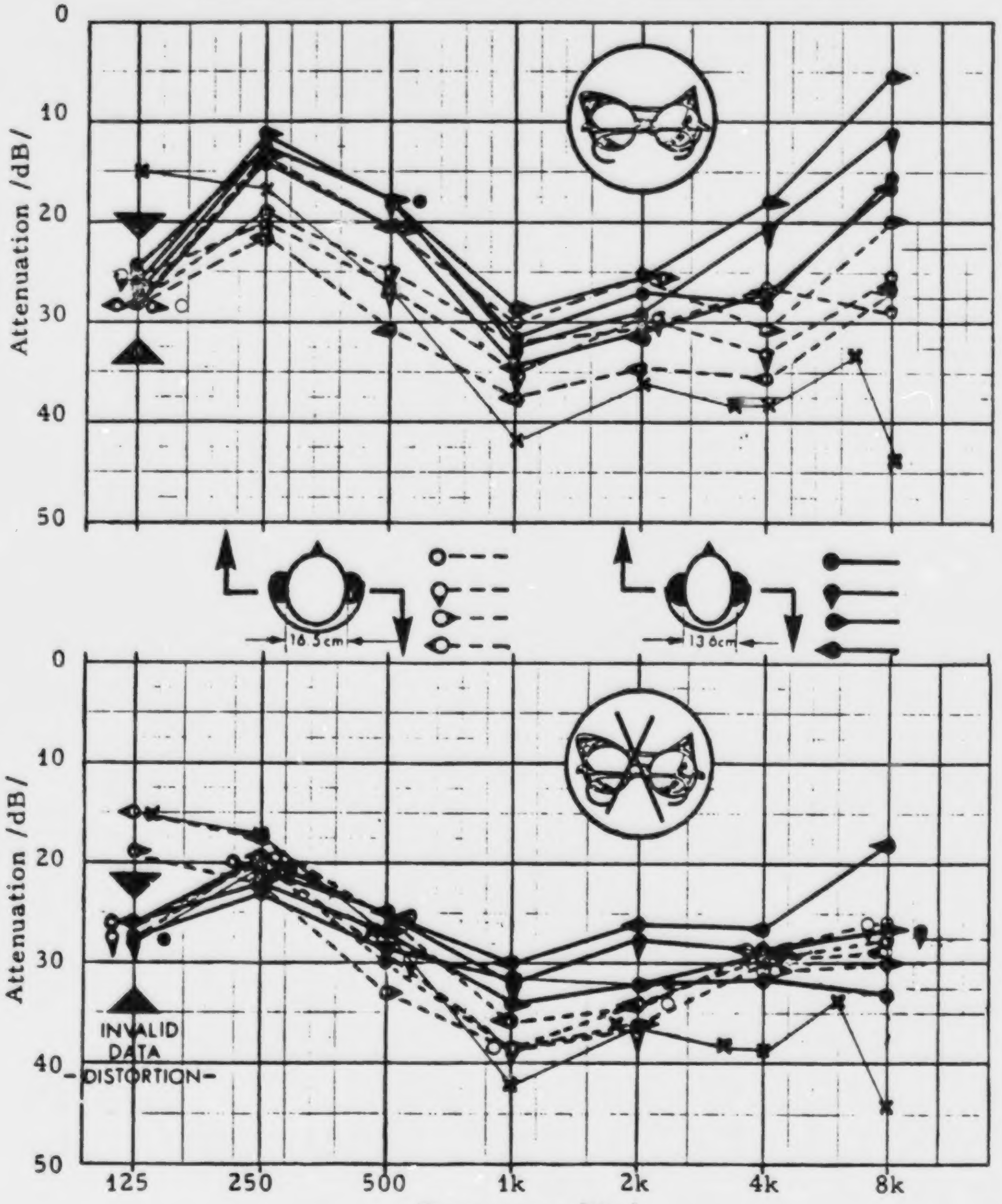


Note: ○ ● Head elevated ◑ ● Head turned right

⚲ ● Head lowered ◐ ● Head turned left

× Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 11 Sound Barrier EM 152, Willson, U.S.A.

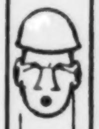
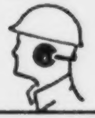
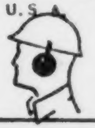
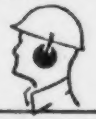
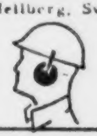
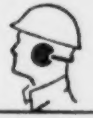


Note: ○ ● Head elevated ◐ ● Head turned right

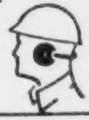
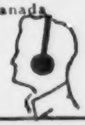
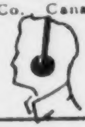
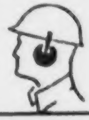
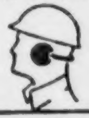
⚲ ⚲ Head lowered ◑ ● Head turned left

✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

Attenuation Reduction Data When the Neck Joint is Flexed and When the Neck is Rotated
(Subject 1 (D = 13.6 cm) used Glasses)

 D (cm)	Hemisphere	No.	1		2		3		4		5	
		Ear Muffs	Model 1675, Amer. Optical, U. S. A. 		Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U. S. A.  ①		Helmet Muffs - (HF), Bilsom, Sweden  ②		Model NO NOISE Helmet Muffs, Hellberg, Sweden  ③		Model NO NOISE, Heliberg, Sweden 	
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)	
			Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd
13.6	Left (L)	Head elevated	27	26	24.5	25	22	22	31	25.5	22	23.5
		Head lowered	27	27	23	23.5	25.5	26	32.5	33	25.5	26.5
		Head turned right	27.5	27	21	21	20	23	28.5	29.5	27	27.5
		Head turned left	26.5	22	26	27	25.5	24.5	35.5	35.5	32	29
		Σ/4	27	25.5	23.6	24.1	23.25	23.9	31.9	30.9	26.6	26.6
	Right (R)	Head elevated	31	30	27	27	29	28.5	27	20	33.5	27
		Head lowered	29	29.5	30.5	34	32.5	32	27	27.5	33.5	26
		Head turned right	32.5	32.5	30	28.5	30	29.5	29	28.5	29	29.5
		Head turned left	28	26.5	25	25.5	30.5	30	24	26.5	22.5	23
		Σ/4	30.1	29.6	28.1	28.75	30.5	30	26.75	25.6	29.6	26.4
	$\frac{L+R}{2}$	(Σ/4 + Σ/4)/2	28.55	27.55	25.85	26.43	26.88	26.95	29.33	28.25	28.1	26.5
			Clamping Force 580 (gwt)		Clamping Force 1005 (gwt)		Clamping Force 730 (gwt)		Clamping Force 980 (gwt)		Clamping Force 1980 (gwt)	

(Cont.)

D (cm)	Hemisphere	No.	6		7		8		9		10	
		Ear Muffs	Model Mark IV, MSA, U.S.A. 		Model 290-S Safe-T-Ear-Muff (gray), Safety Supply Co., Canada 		Model 290-S Safe-T-Ear-Muff (yellow) Safety Supply Co., Canada 		Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.  ④		Model E-905 Straightaway D. Clark, U.S.A. 	
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)	
			Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd
13.6	Left (L)	Head elevated	19.5	20	-	-	29	28.5	24.5	25	30.5	34
		Head lowered	14	14.5	-	-	28	28.5	27.5	27.5	31.5	35.5
		Head turned right	13.5	13.5	-	-	27.5	28	23	23.5	33.5	36.5
		Head turned left	20.5	18.5	-	-	30	30	30.5	31	33	33
		Σ/4	16.9	16.6	-	-	28.6	28.75	26.4	26.75	32.1	34.75
	Right (R)	Head elevated	26	26	-	-	25	27.5	28	27.5	32.5	36.9
		Head lowered	17	16	-	-	22	21.5	26	24.5	32	35.6
		Head turned right	22.5	22.5	-	-	25	25	27	27	28.5	36.4
		Head turned left	15	15.5	-	-	20.5	19	27.5	23.5	34	39.4
		Σ/4	20.1	20	-	-	23.1	23.25	27.1	26.9	31.75	37.1
	$\frac{L+R}{2}$	(Σ/4 + Σ/4)/2	18.45	18.3	-	-	25.85	26	26.75	26.83	31.93	35.93
			Clamping Force 1180 (gwt)		Clamping Force 1230 (gwt)		Clamping Force 1130 (gwt)		Clamping Force 730 (gwt)		Clamping Force 1330 (gwt)	

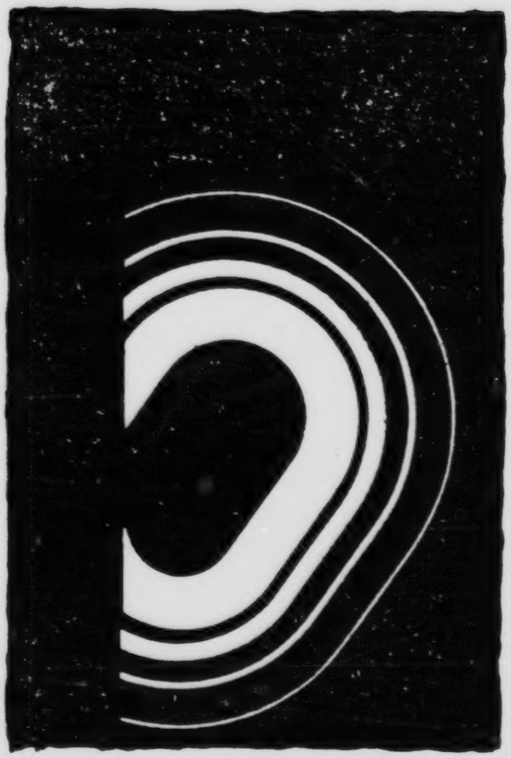
(Cont.)

		No.	11					
	Hemisphere	Ear Muffs	Sound Barrier EM 152 Willson, U.S.A. 		Arithmetic Mean of all Ear Muffs			
D (cm)		Measurements Using Human Heads	Attenuation (dBA)		Mean Attenuation (dBA)			
			Meas.	Est'd	Meas.	St. dev.	Est'd	St. dev.
13.6	Left (L) 	Head elevated	26	26.5	25.6	3.84	25.6	3.79
		Head lowered	23.5	24	25.8	5.15	26.6	5.66
		Head turned right	20	20	24.15	5.74	24.95	6.25
		Head turned left	28.5	28	28.8	4.35	27.85	5.10
		Σ/4	24.5	24.6	26.1	4.45	26.25	4.80
	Right (R) 	Head elevated	29	28	28.8	2.79	27.84	4.13
		Head lowered	27.5	27.5	27.7	5.11	27.41	5.88
		Head turned right	30.5	31	28.4	2.89	29.04	3.86
		Head turned left	26	26	25.3	5.31	25.99	6.42
		Σ/4	28.25	28.1	27.54	3.56	27.57	4.52
	$\frac{L+R}{2}$	(Σ/4 + Σ/4)/2	26.38	26.35	26.82	3.81	26.91	3 05
			Clamping Force 980 (gwt)					

NOTE

* Total noise estimated from the octave-band noise levels given in the Appendix A-2.
Approximate agreement with measured total noise indicates reasonably constant conditions during period of measurement.

① Tested while mounted on helmet; B x 18A Safety Cap, CSA Standard Z 94.1
② Tested while mounted on helmet; Class C, CSA Standard Z 94.1
③ Tested while mounted on helmet; Class C, CSA Standard Z 94.1
④ Tested while mounted on helmet; Class C, CSA Standard Z 94.1



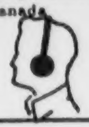
Vignette

Attenuation Reduction Data When the Neck Joint is Flexed and When the Neck is Rotated

(Subject 2 (D = 16.5 cm) used Glasses)

D (cm)	Hemisphere	No.	1		2		3		4		5	
		Ear Muffs	Model 1675, Amer. Optical, U.S.A.		Model 1750 Cap Mounted Hearing Protector, Amer. Optical, U.S.A. ①		Helmet Muffs -(HF), Bilsom, Sweden ②		Model NO NOISE Helmet Muffs, Hellberg, Sweden ③		Model NO NOISE, Hellberg, Sweden	
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)	
			Meas.	Est'd +	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd
16.5	Left (L)	Head elevated	32.5	32	33	32.3	30.5	35	34.5	34.5	28	28
		Head lowered	31.5	31	31.5	31.4	31	34	28	32	28	28
		Head turned right	29	28.5	25	25	25	32	31	30	27.5	26.5
		Head turned left	35	34.5	35.5	35.5	34	34	35.5	36.5	31	29.5
		Σ/4	32	31.5	31.25	31.05	30.13	33.75	32.25	33.25	28.6	28
	Right (R)	Head elevated	32.5	31	31	32	26.5	33.5	33	32	28.5	29
		Head lowered	31.5	32.5	33	33	35	34.5	32	32	27.5	28.5
		Head turned right	35.5	35	34	33	36	36	35.5	33	30.5	32
		Head turned left	28.5	30	32	32	33.5	33.5	31.5	31.5	23.5	25
		Σ/4	32	32.1	32.5	32.5	32.75	34.4	33	32.1	27.5	28.6
	$\frac{L+R}{2}$	(Σ/4 + Σ/4)/2	32	31.8	31.88	31.78	31.44	34.07	32.63	32.68	28.05	28.3
			Clamping Force 780 (gwt)		Clamping Force 1355 (gwt)		Clamping Force 930 (gwt)		Clamping Force 1230 (gwt)		Clamping Force 2580 (gwt)	

(Cont.)

	Hemisphere	No.	6		7		8		9		10	
		Ear Muffs	Model Mark IV, MSA, U.S.A.		Model 290-S Safe-T-Ear-Muff (gray), Safety Supply Co., Canada 		Model 290-S Safe-T-Ear-Muff (yellow) Safety Supply Co., Canada		Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A. ④		Model E-805 Straightaway D. Clark, U.S.A.	
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)	
			Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd
16.5	Left (L)	Head elevated	32.5	31.5	-	-	37	36	32.5	33	31	36.5
		Head lowered	34.5	34.5	-	-	36	35.5	29.5	29.5	30.5	35.5
		Head turned right	30	28.5	-	-	39	38.5	29	29.5	30.5	36.5
		Head turned left	35.5	35	-	-	35.5	34	34.5	35.5	35.5	39.5
		Σ/4	33.1	32.4	-	-	36.9	36	31.4	31.9	31.9	37
	Right (R)	Head elevated	37	37	-	-	38.5	40.5	24.5	24.5	36.5	34
		Head lowered	39.5	40	-	-	38.5	39	34	32.5	33.5	35.5
		Head turned right	38.5	38	-	-	36	36.5	36	37	36	36.5
		Head turned left	38	37	-	-	42	41.5	31.5	34.5	32.5	33
		Σ/4	38.25	38	-	-	38.75	39.4	31.5	32.1	34.6	34.75
	$\frac{L+R}{2}$	(Σ/4 + Σ/4)/2	35.68	35.2	-	-	37.83	37.7	31.45	32	33.25	35.88
			Clamping Force 1580 (gwt)		Clamping Force 1480 (gwt)		Clamping Force 1330 (gwt)		Clamping Force 1005 (gwt)		Clamping Force 1930 (gwt)	

(Cont.)

 D (cm)	Hemisphere	No.	11					
		Ear Muffs	Sound Barrier EM 152 Willson, U.S.A. 		Arithmetic Mean of all Ear Muffs			
		Measurements Using Human Heads	Attenuation (dBA)		Mean Attenuation (dBA)			
			Meas.	Est'd	Meas.	St. dev.	Est'd	St. dev.
16.5	Left (L) 	Head elevated	29	28.5	32.05	2.61	32.73	2.90
		Head lowered	30.5	30.5	31.1	2.55	32.19	2.59
		Head turned right	27	27	29.3	4.01	30.2	4.33
		Head turned left	33.5	35.5	34.55	1.44	34.95	2.49
		Σ/4	30	30.4	31.75	2.23	32.52	2.64
	Right (R) 	Head elevated	33	32	32.1	4.59	32.55	4.30
		Head lowered	33	32.5	33.75	3.43	34	3.42
		Head turned right	34.5	34	35.25	2.04	35.1	2.01
		Head turned left	35	32	32.8	5.01	33	4.32
		Σ/4	33.9	32.6	33.48	3.26	33.66	3.14
	$\frac{L+R}{2}$	(Σ/4 + Σ/4)/2	31.95	31.5	32.62	2.34	33.09	5.78
			Clamping Force 1280 (gwt)					

NOTE

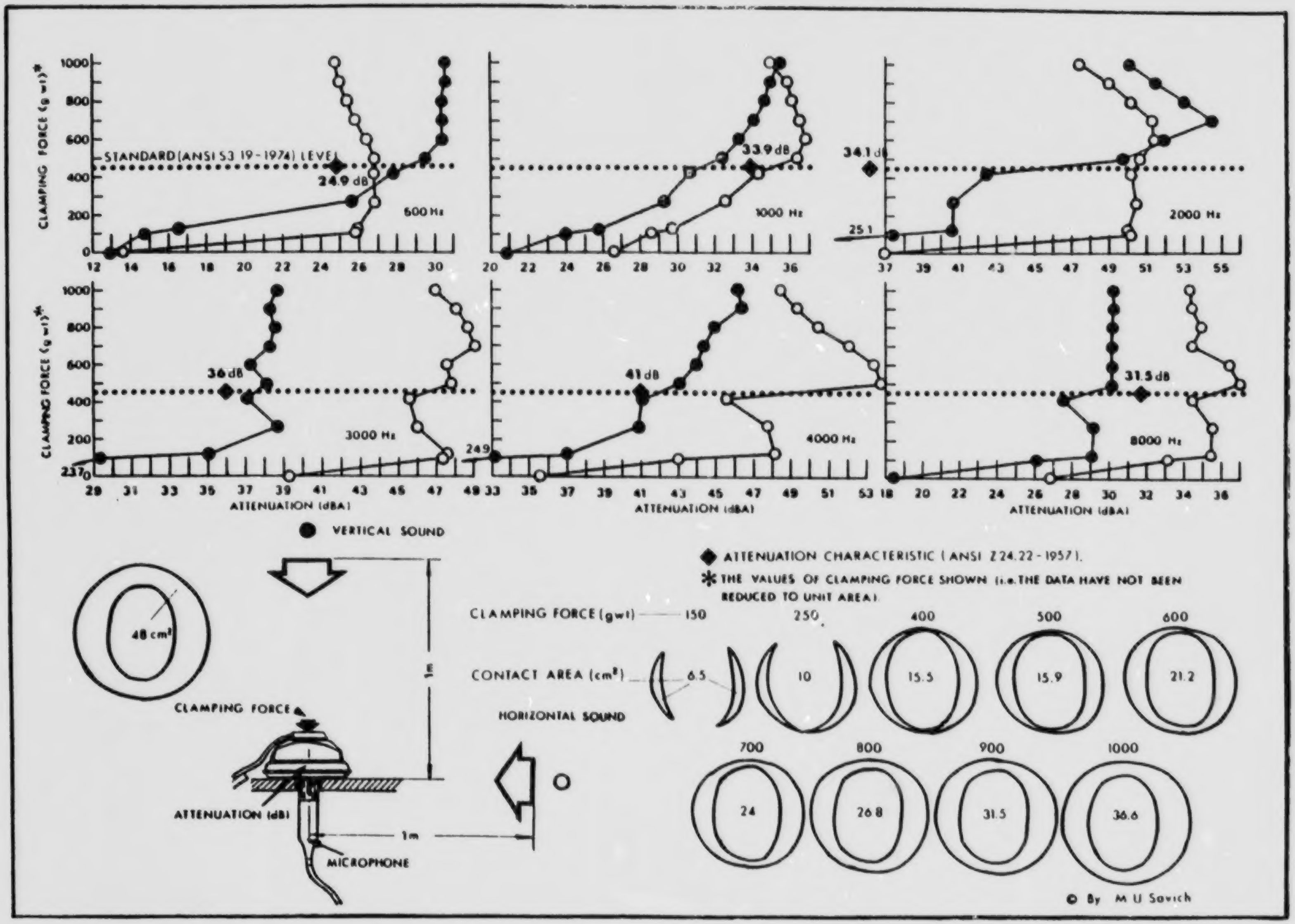
+ Total noise estimated from the octave-band noise levels given in the Appendix A-2.
Approximate agreement with measured total noise indicates reasonably constant conditions during period of measurement.

① Tested while mounted on helmet; B x 18A Safety Cap, CSA Standard Z 94.1
② Tested while mounted on helmet; Class C, CSA Standard Z 94.1
③ Tested while mounted on helmet; Class C, CSA Standard Z 94.1
④ Tested while mounted on helmet; Class C, CSA Standard Z 94.1

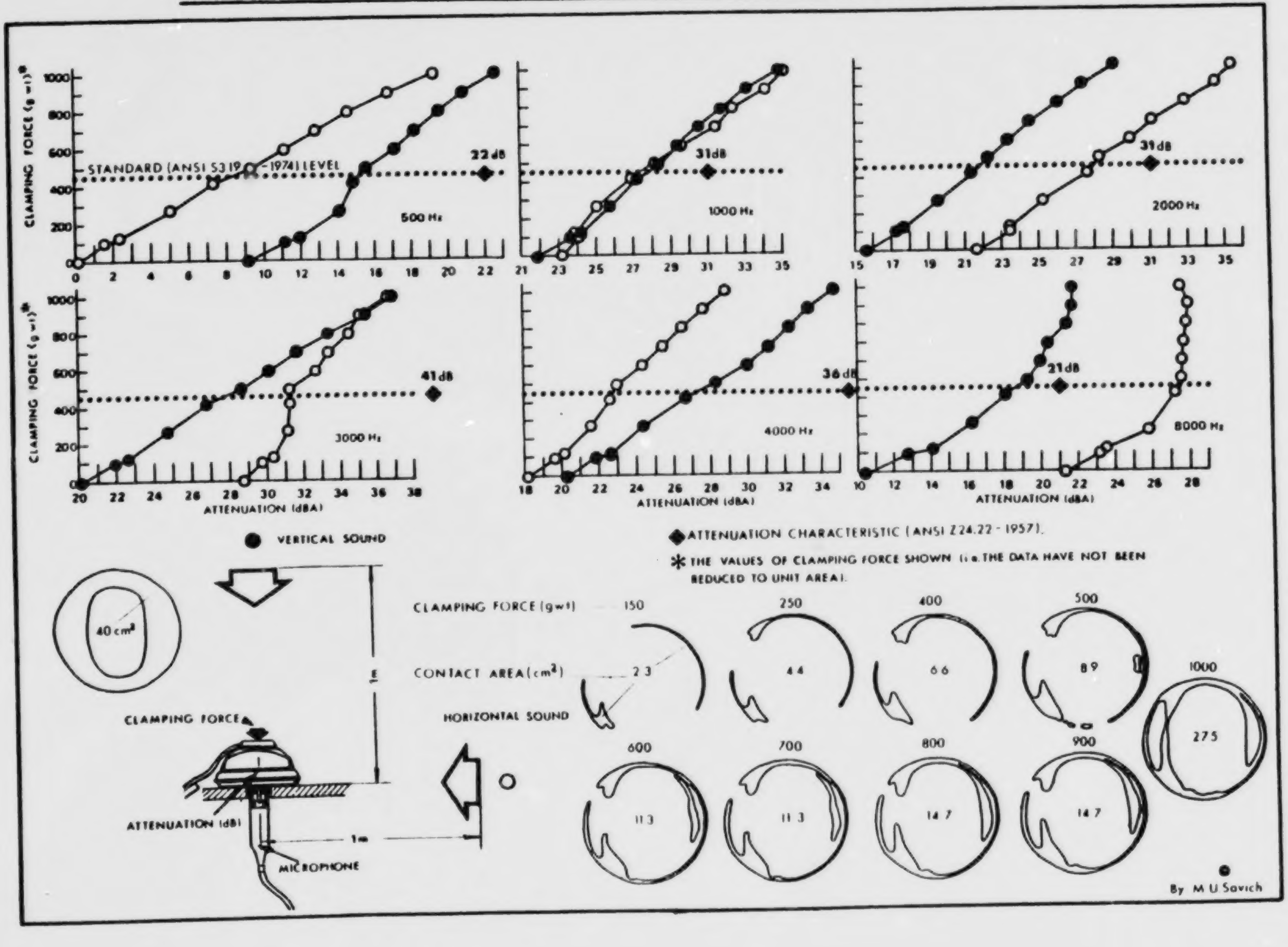
APPENDIX C

Physical Test

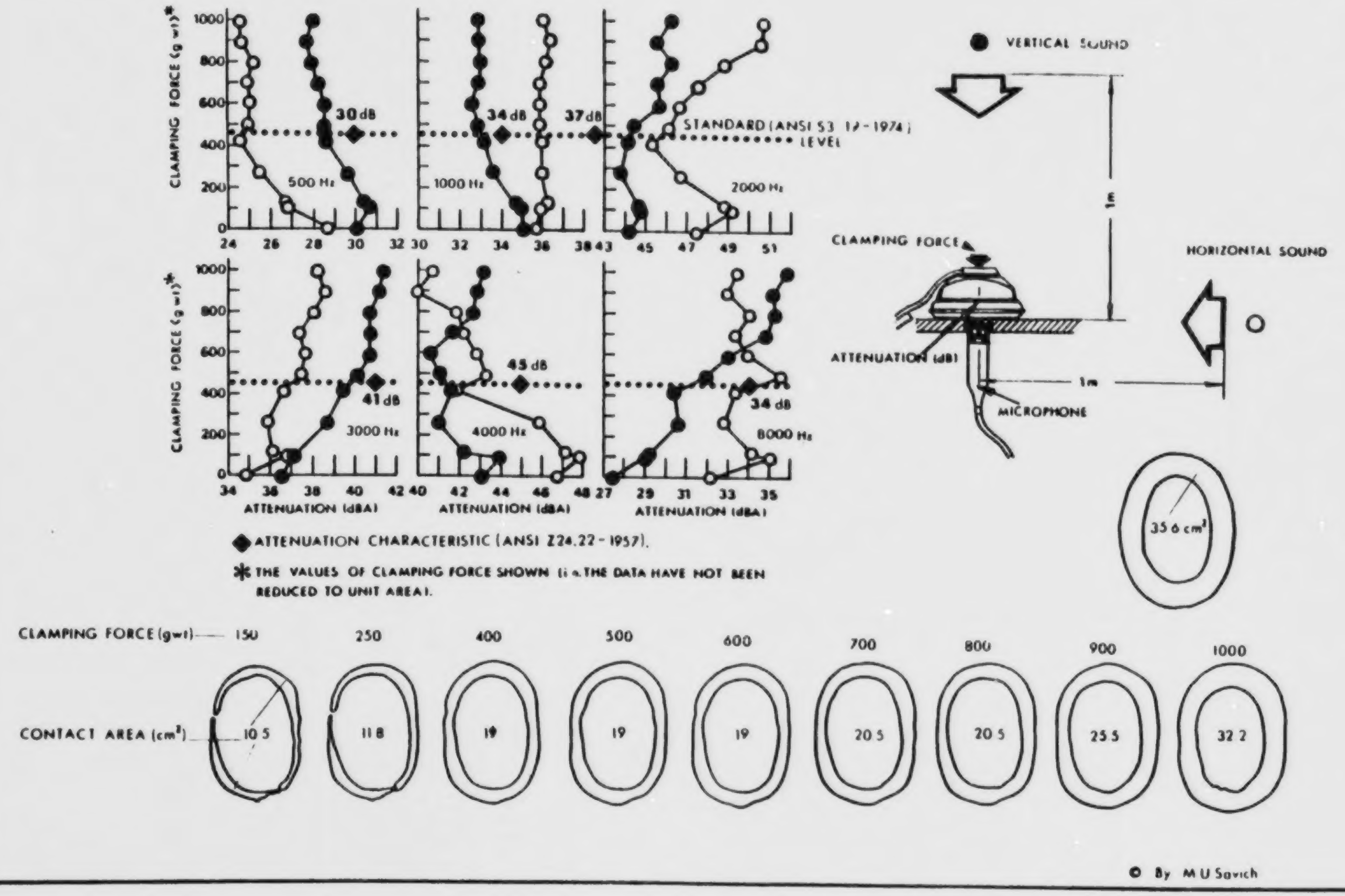
No. 1 Model 1675, American Optical, U.S.A.



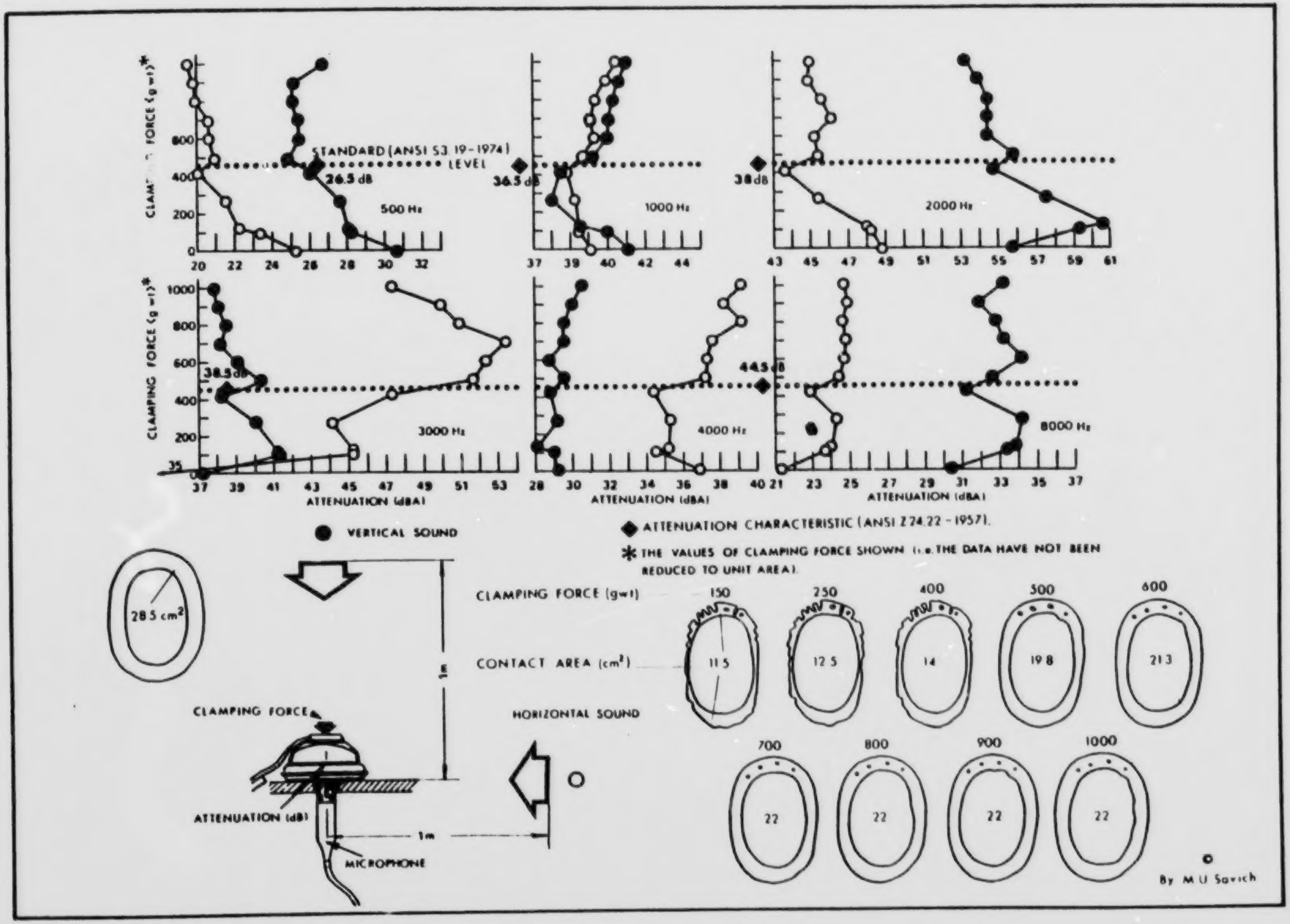
No. 2 Model 1750 Cap Mounted Hearing Protector, American Optical, U.S.A.



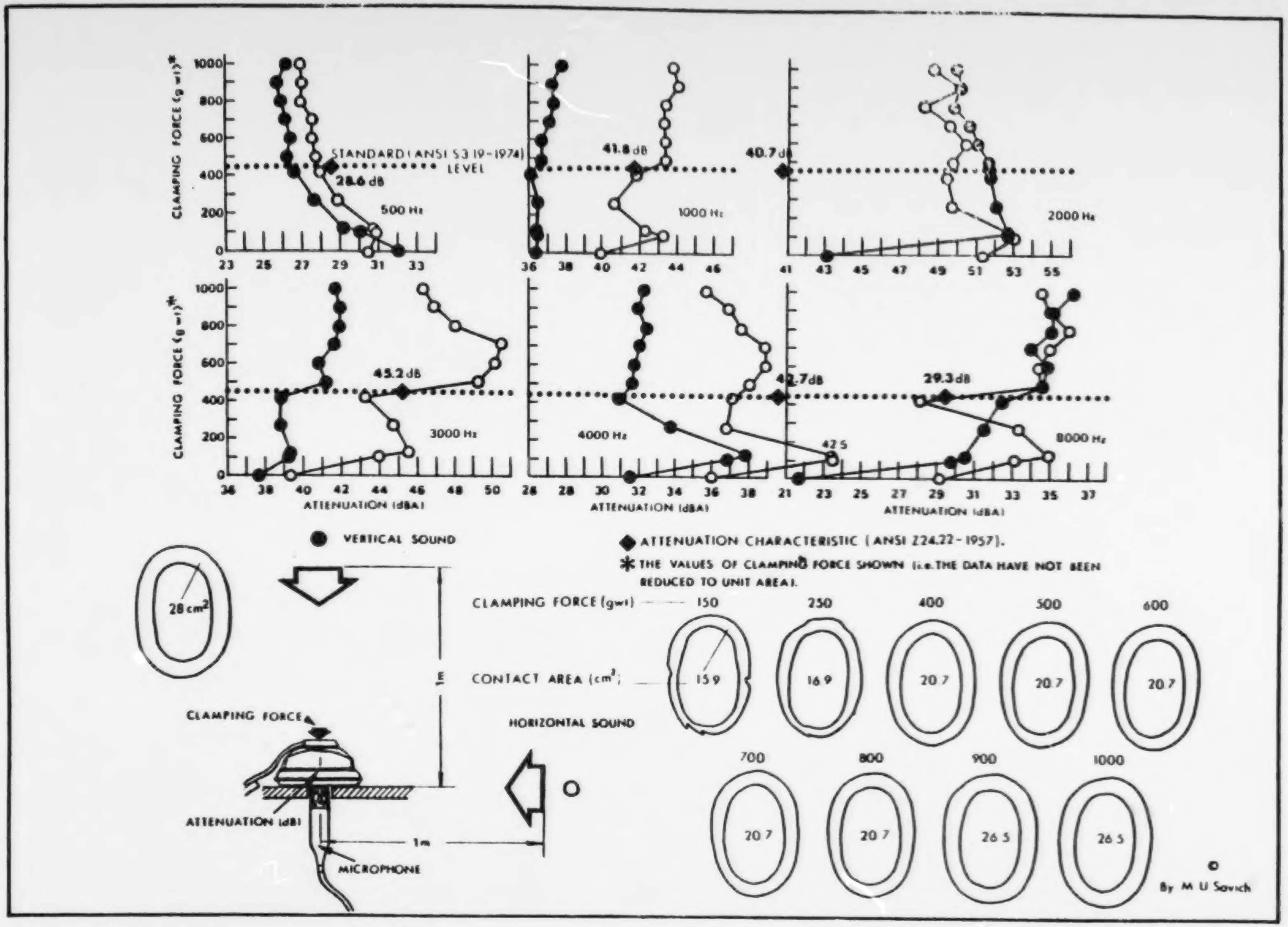
No. 3 Helmet Muffs - (HF), Bilsom, Sweden



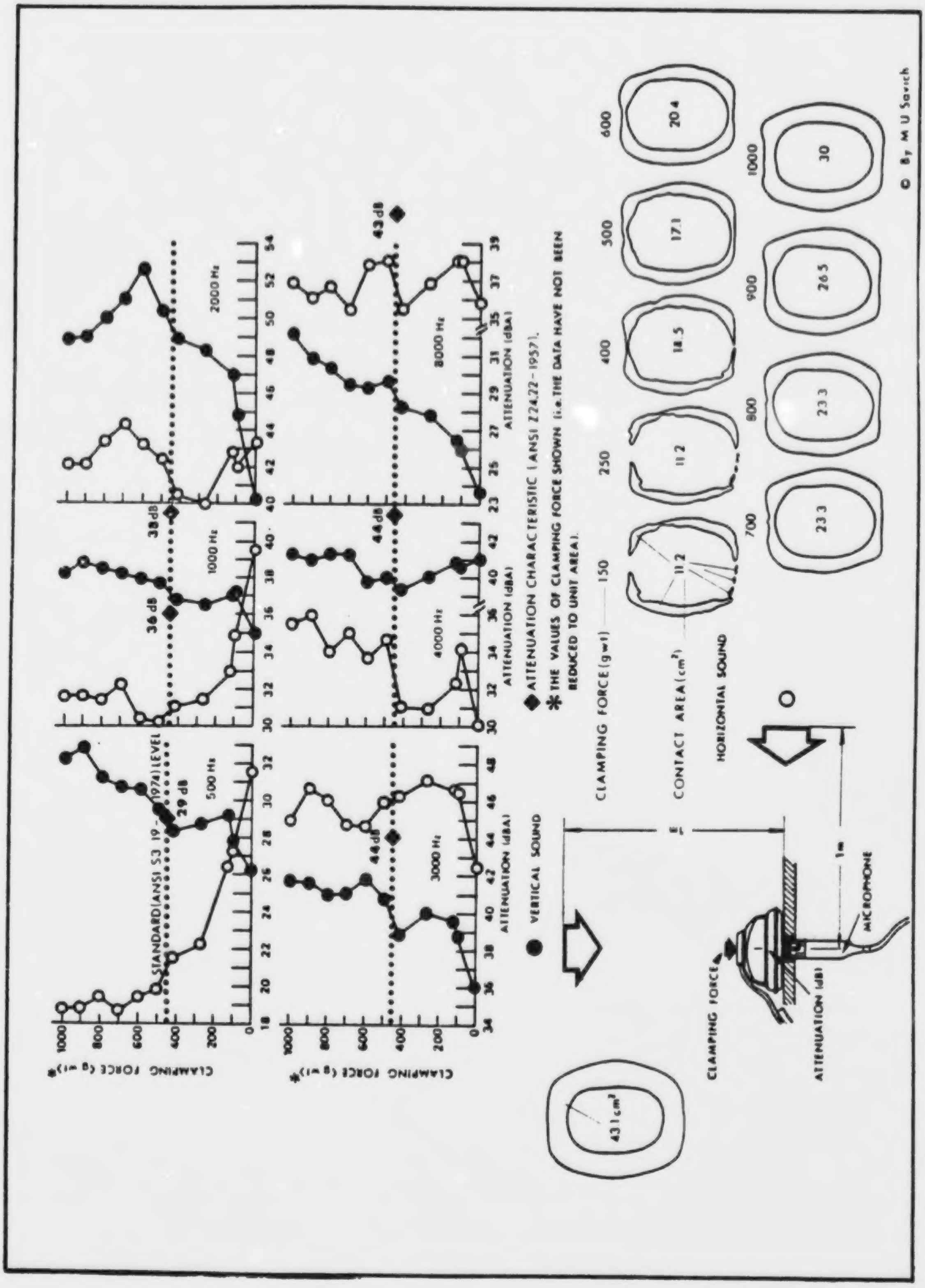
No. 4 Model NO NOISE Helmet Muffs, Hellberg, Sweden



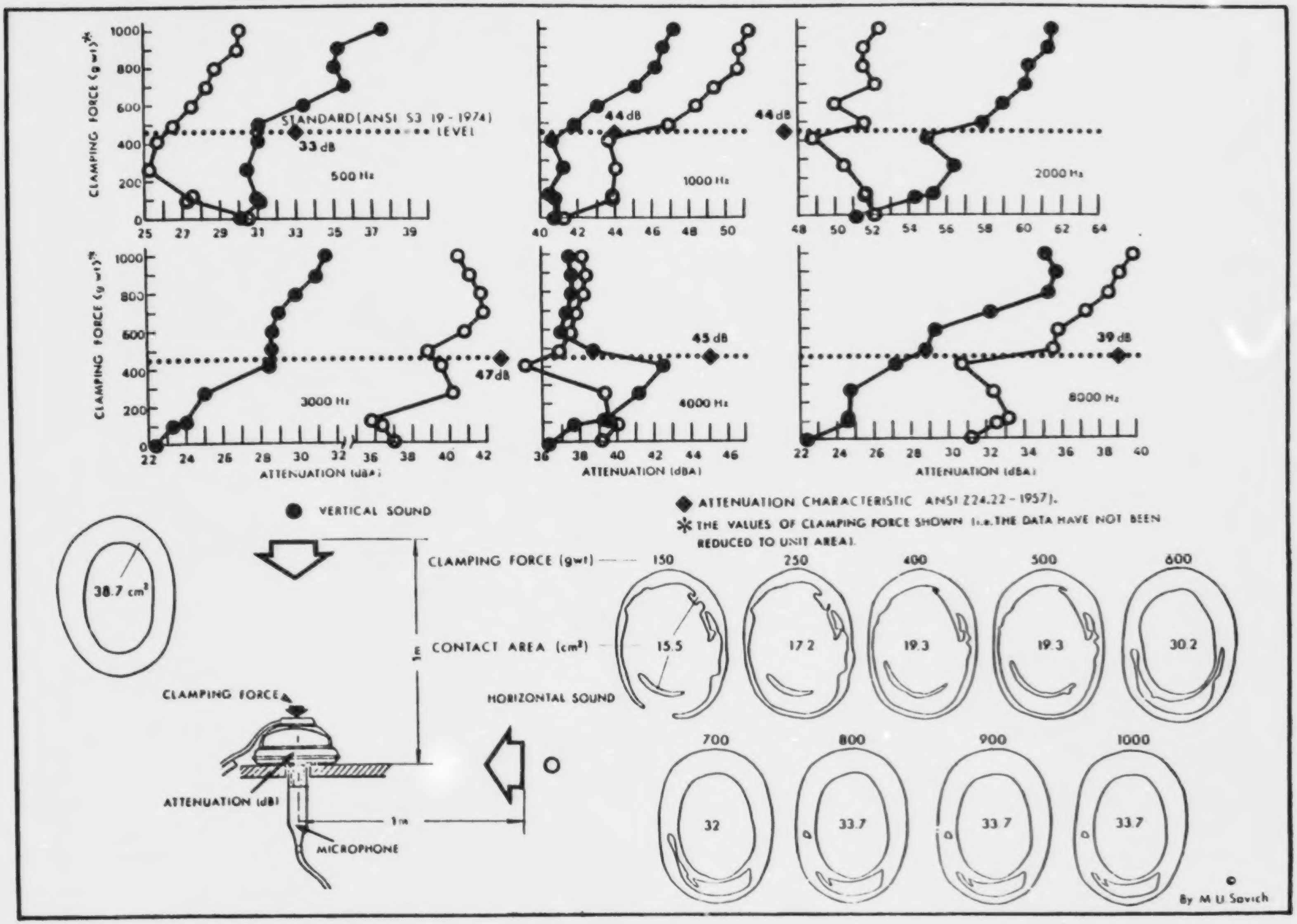
No. 5 Model NO NOISE, Hellberg, Sweden



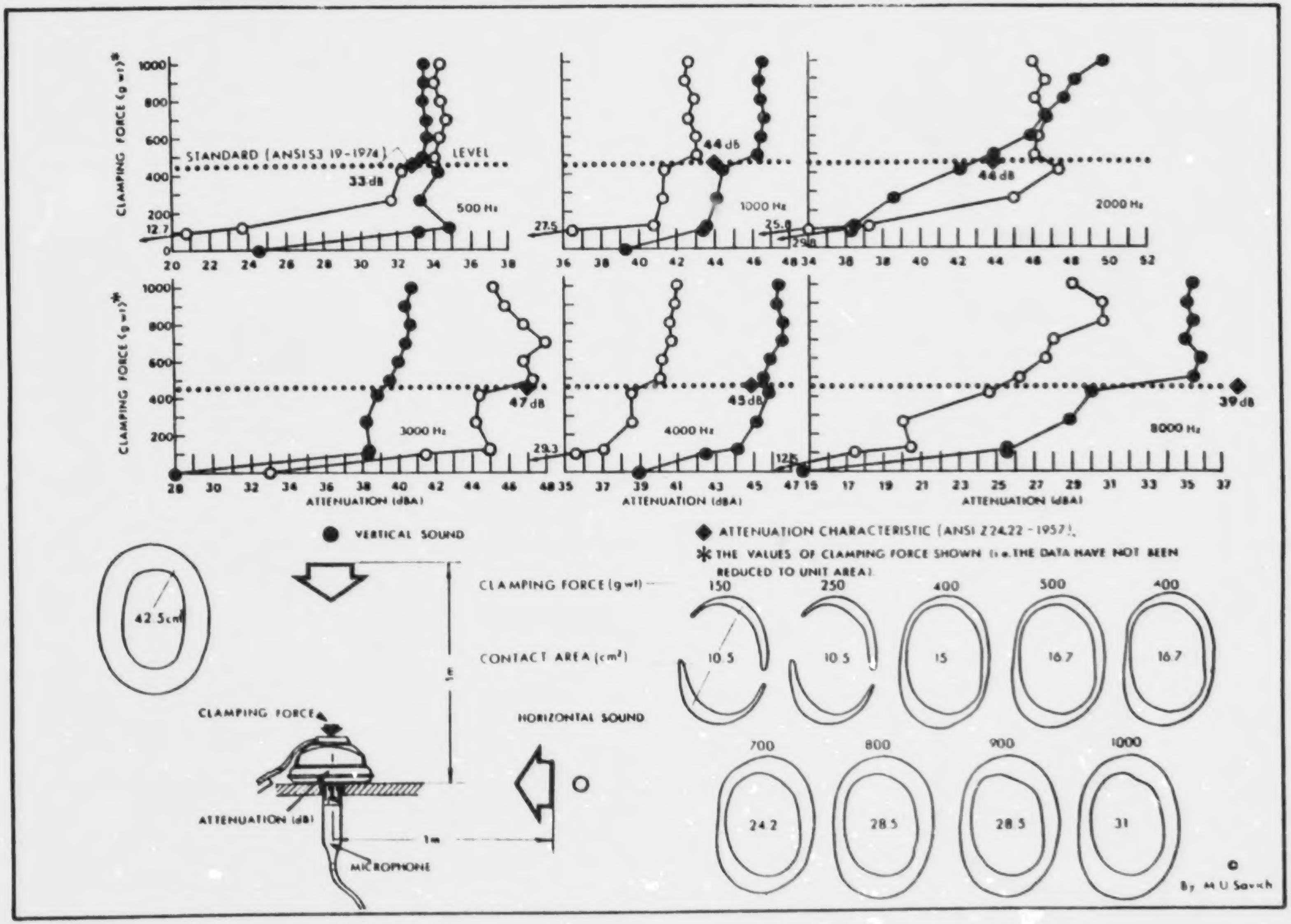
No. 6 Model Mark IV, MSA, U.S.A.



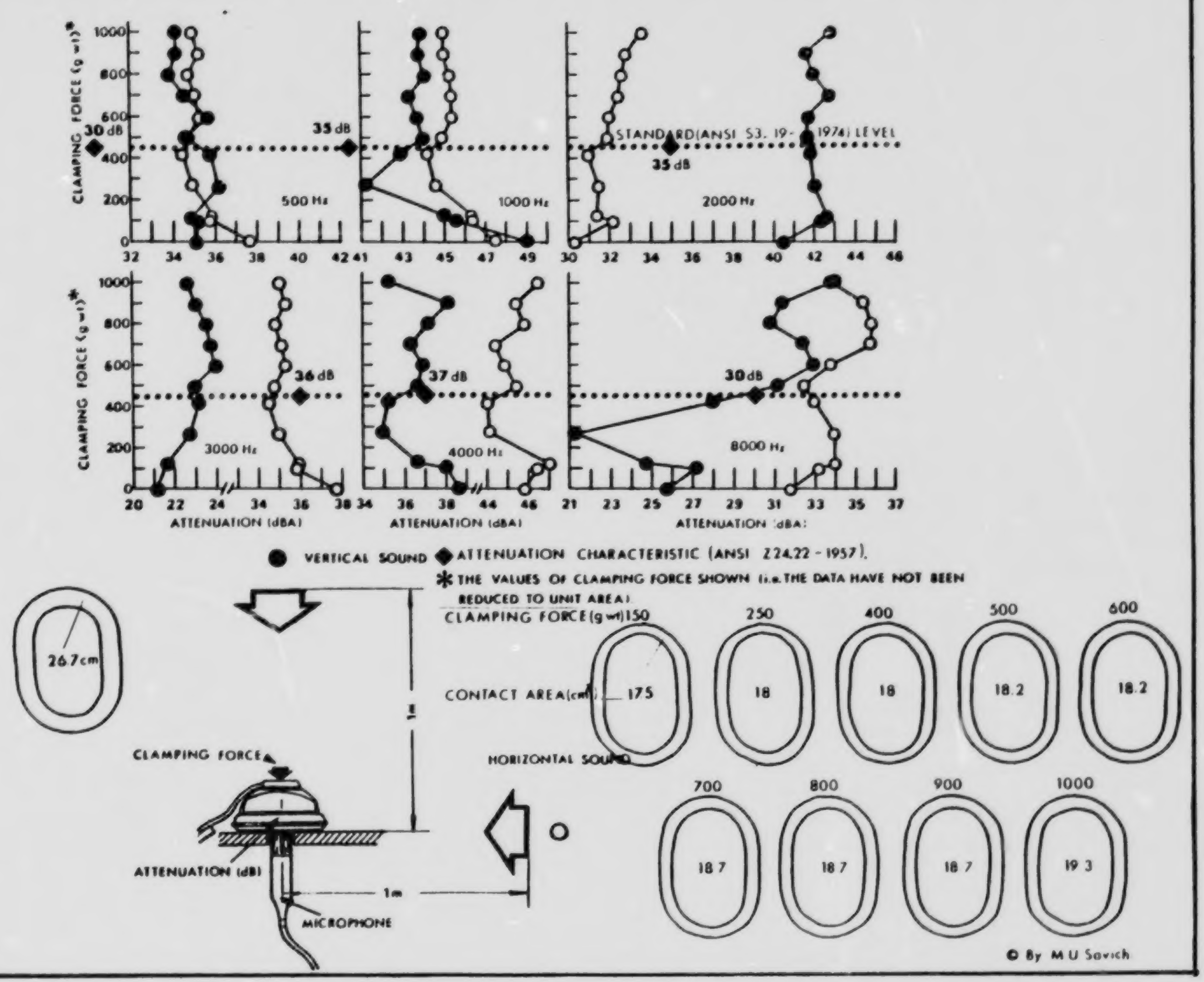
No. 7 Model 290-S Safe-T-Ear Muff (gray), Safety Supply Co., Canada



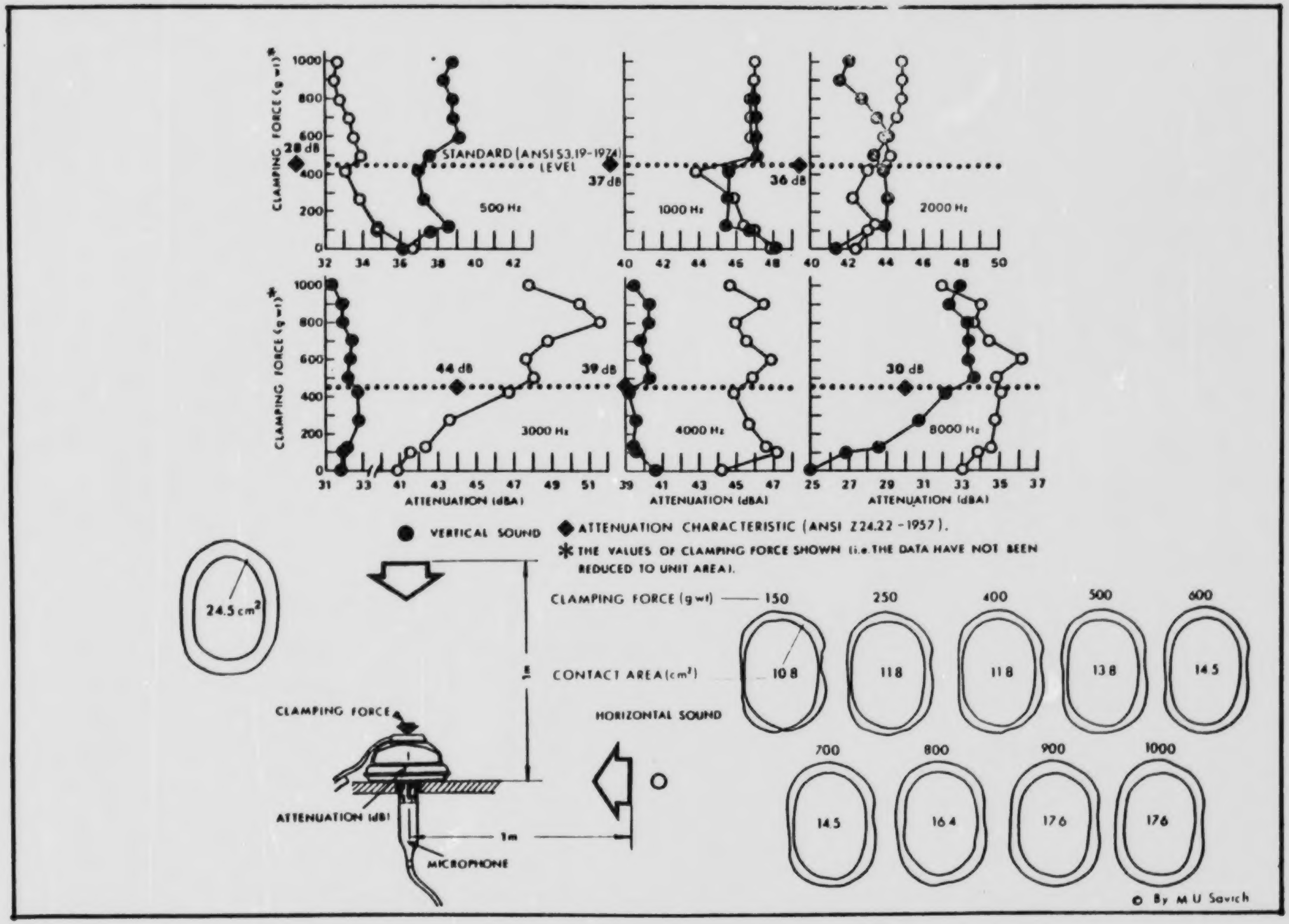
No. 8 Model 290-S Safe-T-Ear Muff (yellow), Safety Supply Co., Canada



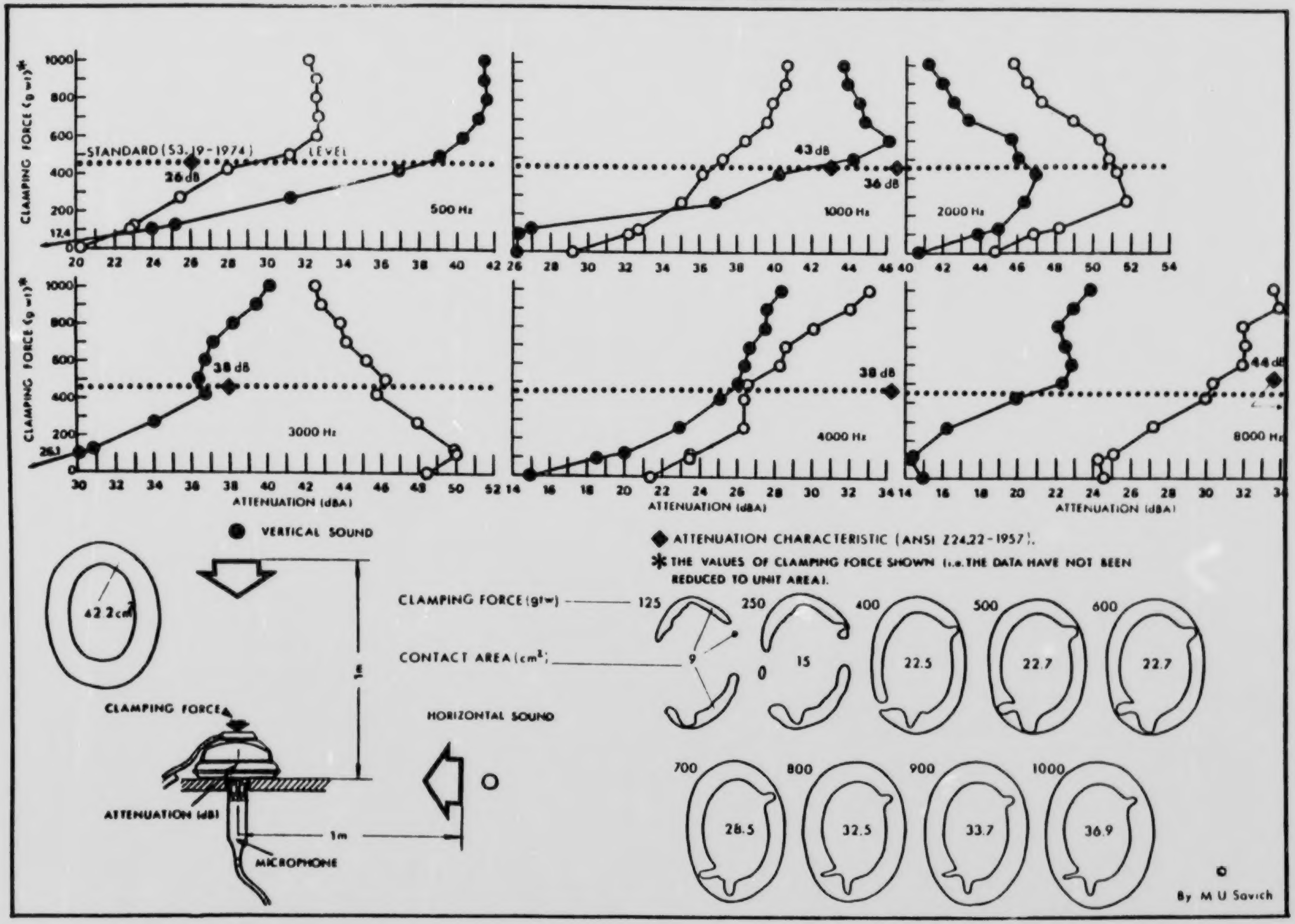
No. 9 Model E-705 Straightaway Helmet Muffs, D. Clark, U.S.A.



No. 10 Model E-805 Straightaway, D. Clark, U.S.A.



No. 11 Sound Barrier EM 152, Willson, U.S.A.



APPENDIX D

Ear Muff Noise Attenuation Survey Forms

ELLIOT LAKE LABORATORY, CANMET, E.M.R.

SHEET: 4

Ear Muff Noise Attenuation Survey Form

EQUIPMENT TESTED (SEE OTHER SIDE FOR DETAILS): JUMBO, Seco Drills - 3

EAR MUFF: MSA Mark IV

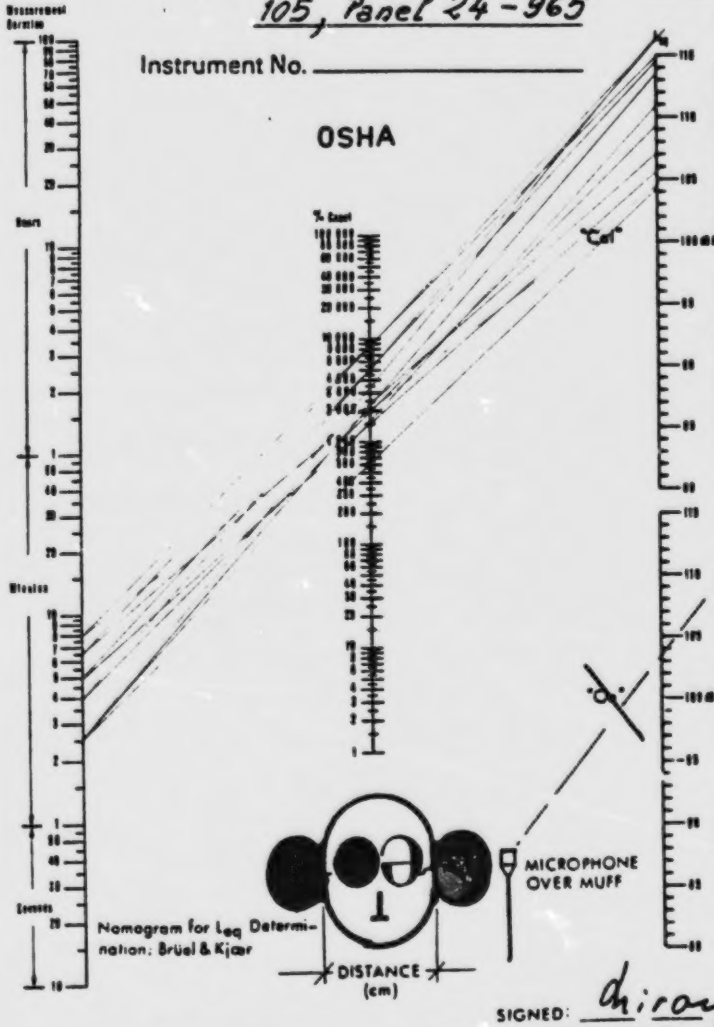
Date: May 19, 1977

✓ 2 3 COMFORT

Location: Local Mines Ltd. 105, Panel 24 - 965

5 6 7 8 [✓ 9] 10 11 12 ($) PRICE/UNIT

Instrument No. ______



Measurement Duration
Hours
Minutes
Seconds
OSHA
% Count
"Cal"
MICROPHONE OVER MUFF
DISTANCE (cm)
Nomogram for Leq Determination; Brüel & Kjær

RIGHT SIDE

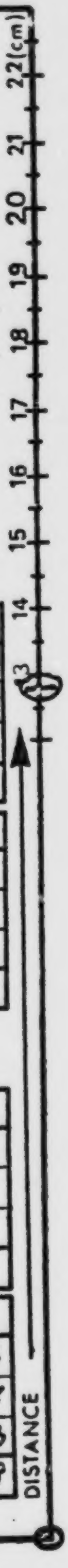
%Count	Time (min)	Leq (dBA)
3480	2:30	117.0
5000	4:00	116.4
8580	6:30	116.4
	3/3	116.6

%Count	Time (min)	Leq (dBA)
1570	2:30	111.0
1970	4:00	109.2
2450	6:30	107.0
	3/3	109.2

LEFT SIDE

%Count	Time (min)	Leq (dBA)
2300	2:30	113.8
5250	5:00	114.3
8600	8:00	115.0
	3/3	114.4

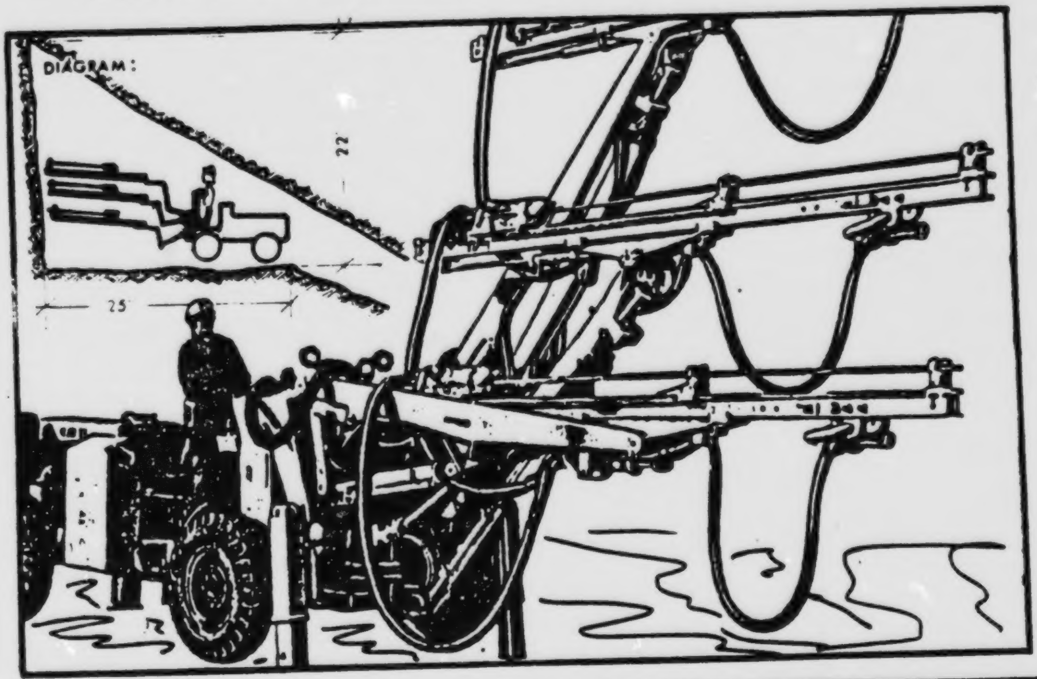
%Count	Time (min)	Leq (dBA)
630	2:30	104.3
1500	5:00	105.7
2060	8:00	104.3
	3/3	104.8



22 (cm)
21
20
19
18
17
16
15
14
13
DISTANCE

SIGNED: Miroy Savich

ELLIOT LAKE LABORATORY, CANMET, E.M.R.



SUBJECT: SECO (S.AFRICA)- JUMBO, Seco Drills-3

Model: ____________ Manufacturer: SECO Serial: ________

Rated Speed and Capacity: ________________________

Description: Three drill jumbos can be used in driving drifts or tunnels with great variations in cross section.

TECHNICAL DATA:

Steel type: ________________

Length: ______________ metres

Bit Type: ________________

Muffler Type: ________________

Air Pressure Supplied: _____ bars

Water Pressure Supplied: _______ bars

Airflow: ______________ m^3/min

Blow Rate: ______________ blow/min

Penetration: ______________ m/min

Rock Type: Uraniferous Conglomerat

NOTES: Jumbo operator should wear ear muffs and ear plugs.

ELLIOT LAKE LABORATORY, CANMET, E.M.R.

SHEET: 3

Ear Muff Noise Attenuation Survey Form

EQUIPMENT TESTED (SEE OTHER SIDE FOR DETAILS): WAGON DRILL HYDROFORE - MONTABERT -

EAR MUFF: NO NOISE Hellberg Protection AB, Sweden

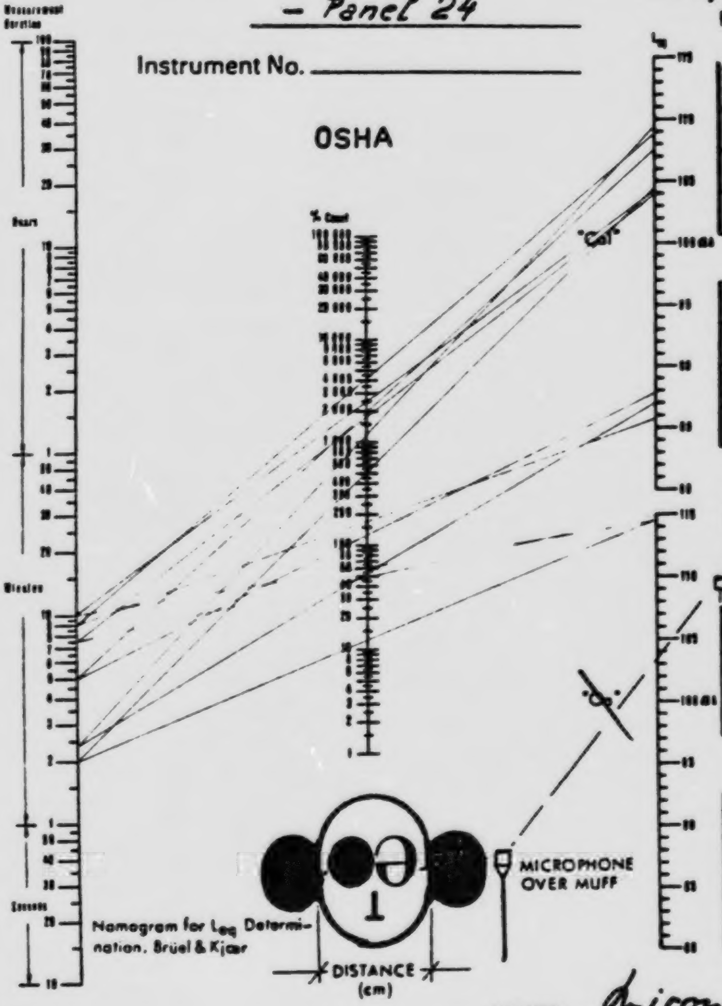
Date: May 16, 1977

1 2 [✓ 3] COMFORT

5 6 7 [✓ 8] 9 10 11 12 ($) PRICE/UNIT

Location: Local Mines Ltd. - Panel 24

Instrument No. ______________



Nomogram for Leq Determination, Brüel & Kjær

RIGHT SIDE

%Count	Time (min)	Leq (dBA)
1250	2:15	109.5
2070	5:00	107.7
4470	9:00	108.8
	3/3	108.7

%Count	Time (min)	Leq (dBA)
58	2:15	87
130	5:00	88
170	9:00	86
	3/3	87

LEFT SIDE

%Count	Time (min)	Leq (dBA)
530	2:00	104.5
1690	7:30	104
2510	10:30	104.2
	3/3	104.2

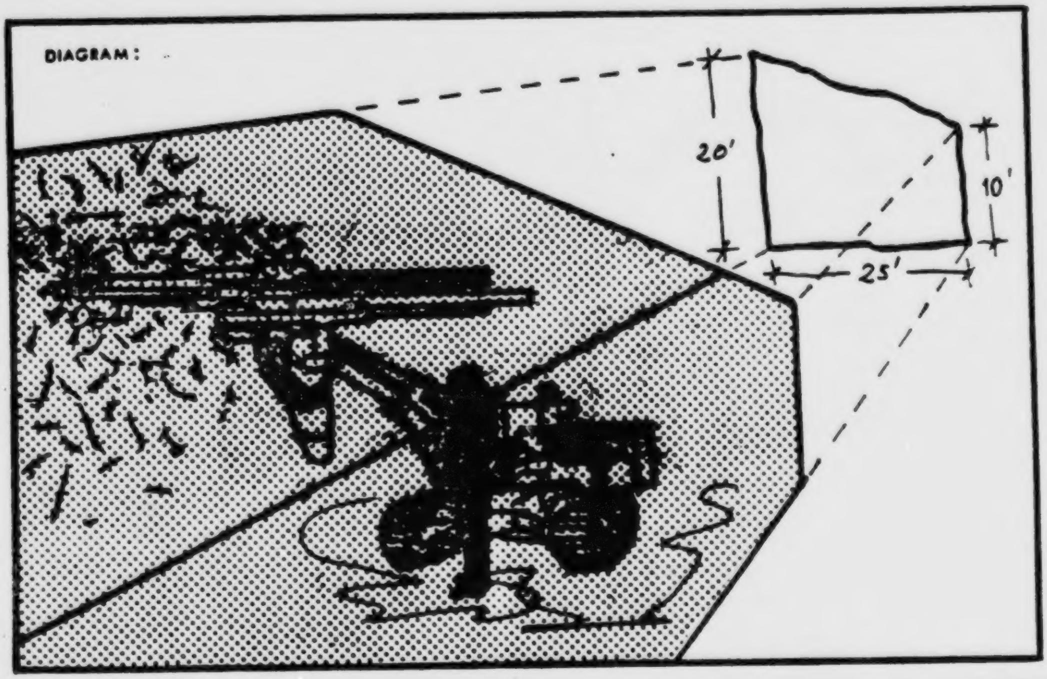
%Count	Time (min)	Leq (dBA)
13	2:00	~77
50	7:30	~77
62	10:30	~77
	3/3	77

DISTANCE

SIGNED: Lirony Savich

ELLIOT LAKE LABORATORY, CANMET, E.M.R.

DIAGRAM:



SUBJECT: TRACK MOUNTED WAGON DRILL HYDROFORE

Model: H 100 Manufacturer: Montabert Serial: ____

Rated Speed and Capacity: ____

Description: Montabert offers an option of the H 100: the H 100 FR drifter. During extraction of rods, the piston strikes at full power on shank, without transmission of shocks to component parts of drifter. Rod extraction, without damaging the equipment is thus made far easier.

TECHNICAL DATA:

Steel type: hex. 38 (1½")
Length: 1.83 (6Ft) metres
Bit Type: Cross, ϕ51mm (2")
Muffler Type: ____
Air Pressure Supplied: 100 bars

Waterflushing requirements: 20l/min (4½ imp gal)
Airflow: 4.5 (150) m³/min
Blow Rate: 1400 blow/min
Penetration: ~0.7 (28 ins/min) m/min
Rock Type: Uraniferous Conglomerate

NOTES: Drill operator should wear ear muffs and ear plugs.

ELLIOT LAKE LABORATORY, CANMET, E.M.R.

SHEET: 9

Ear Muff Noise Attenuation Survey Form

EQUIPMENT TESTED (SEE OTHER SIDE FOR DETAILS): JAW CRUSHER

EAR MUFF: David Clark Co. Inc. Model E-705

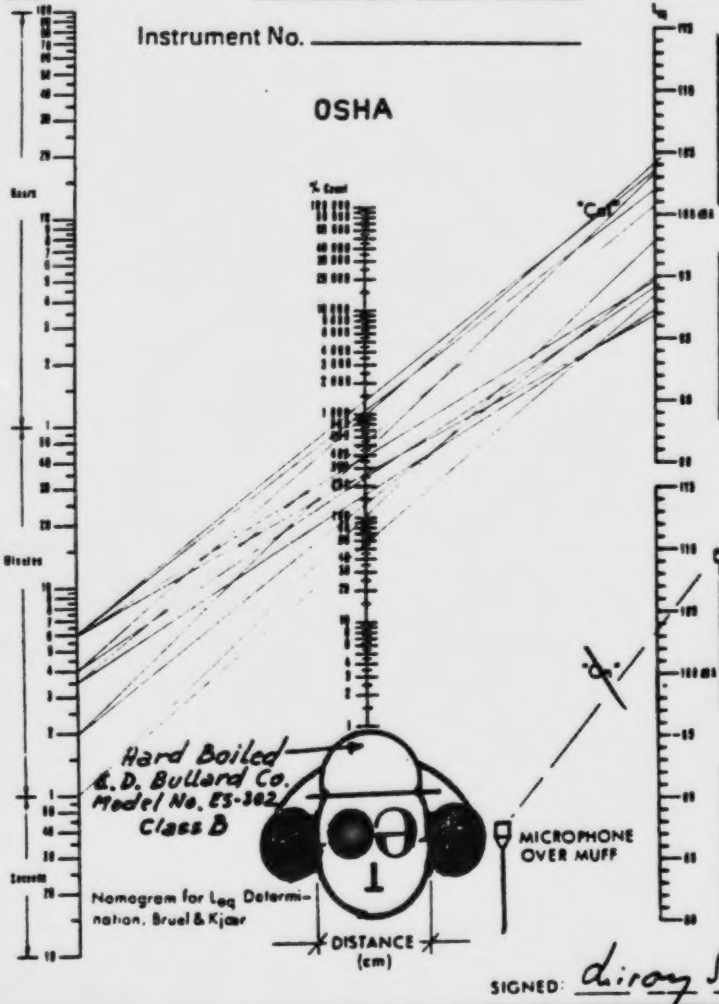
Date: May 13, 1977

[✓ 1] 2 3 COMFORT

5 6 7 8 [✓ 9] 10 11 12 ($) PRICE/UNIT

Location: Local Mines Ltd. Crusher

Instrument No. ______


Measurement Duration
Hours
Minutes
Seconds
OSHA
% Count
"Cal"
L_{eq}
Hard Boiled
E.D. Bullard Co.
Model No. ES-302
Class B
MICROPHONE OVER MUFF
DISTANCE (cm)
Nomogram for L_{eq} Determination, Bruel & Kjaer

RIGHT SIDE

%Count	Time (min)	L_{eq}(dBA)
420	2:00	103.2
950	4:00	104.3
1360	6:00	103.5
	Σ/3	103.7

%Count	Time (min)	L_{eq}(dBA)
140	2:00	~ 95
240	4:00	94.2
370	6:00	94.8
	Σ/3	94.7

LEFT SIDE

%Count	Time (min)	L_{eq}(dBA)
100	1:00	98.1
540	3:30	100.9
1015	6:00	102.1
	Σ/3	100.3

%Count	Time (min)	L_{eq}(dBA)
57	1:00	94.5
160	3:30	92.3
262	6:00	92
	Σ/3	92.9

22 (cm)
21
20
19
18
17
16
15
14
13
DISTANCE

SIGNED: Leroy Savich

ELLIOT LAKE LABORATORY, CANMET, E.M.R.

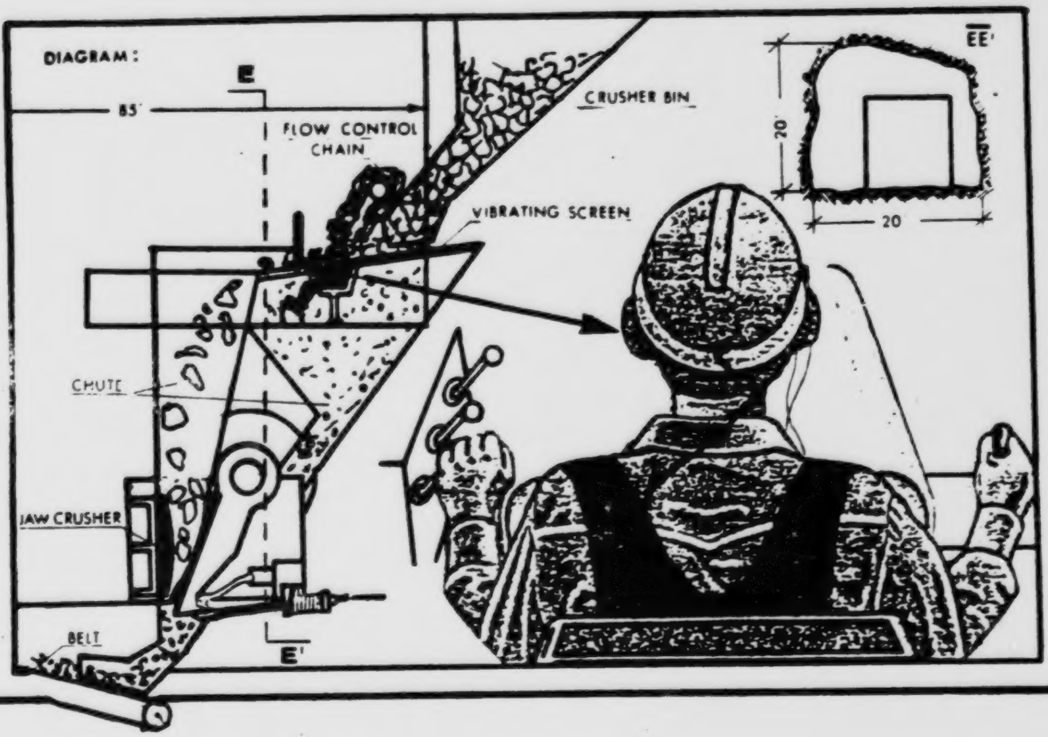


DIAGRAM:
E
85'
FLOW CONTROL CHAIN
CRUSHER BIN
VIBRATING SCREEN
CHUTE
JAW CRUSHER
BELT
E'
EE'
20'
20

SUBJECT: JAW CRUSHER

Model: ____ Manufacturer: ____ Serial: ____
Rated Speed and Capacity: ~ 600 t/h to 700 t/h
Description: ____

TECHNICAL DATA:

Steel type: ____
Length: ____ metres
Bit Type: ____
Muffler Type: ____
Air Pressure Supplied: ____ bars

Water Pressure Supplied: ____ bars
Airflow: ____ m^3/min
Blow Rate: ____ blow/min
Penetration: ____ m/min
Rock Type: Uraniferous Conglomerate

NOTES: Measurements taken at crusher operator control panel. Crusher operator should wear ear muffs, or ear plugs.

ELLIOT LAKE LABORATORY,CANMET,E.M.R.

SHEET:....

Ear Muff Noise Attenuation Survey Form

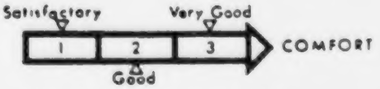
EQUIPMENT TESTED(SEE OTHER SIDE FOR DETAILS):

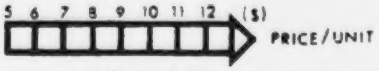
EAR MUFF:

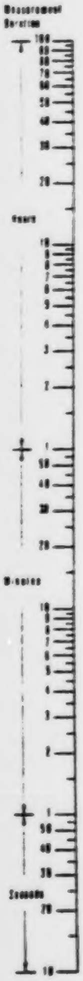
Date:

Location:

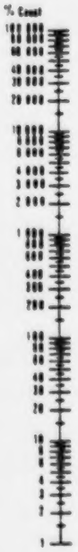
Instrument No.


Satisfactory
Very Good
1
2
3
Good
COMFORT

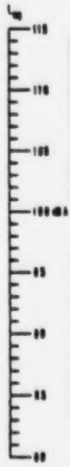

5 6 7 8 9 10 11 12 ($)
PRICE/UNIT


Measurement Duration
100
20
Hours
10
1
Minutes
10
1
Seconds
10

OSHA



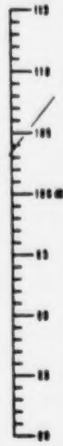
RIGHT SIDE



%Count	Time (min)	Leq (dBA)
	Σ/3	

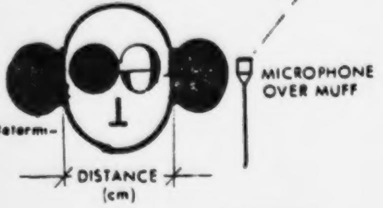
%Count	Time (min)	Leq (dBA)
	Σ/3	

LEFT SIDE



%Count	Time (min)	Leq (dBA)
	Σ/3	

%Count	Time (min)	Leq (dBA)
	Σ/3	


MICROPHONE OVER MUFF
DISTANCE (cm)

Nomogram for L_{eq} Determination, Bruel & Kjaer

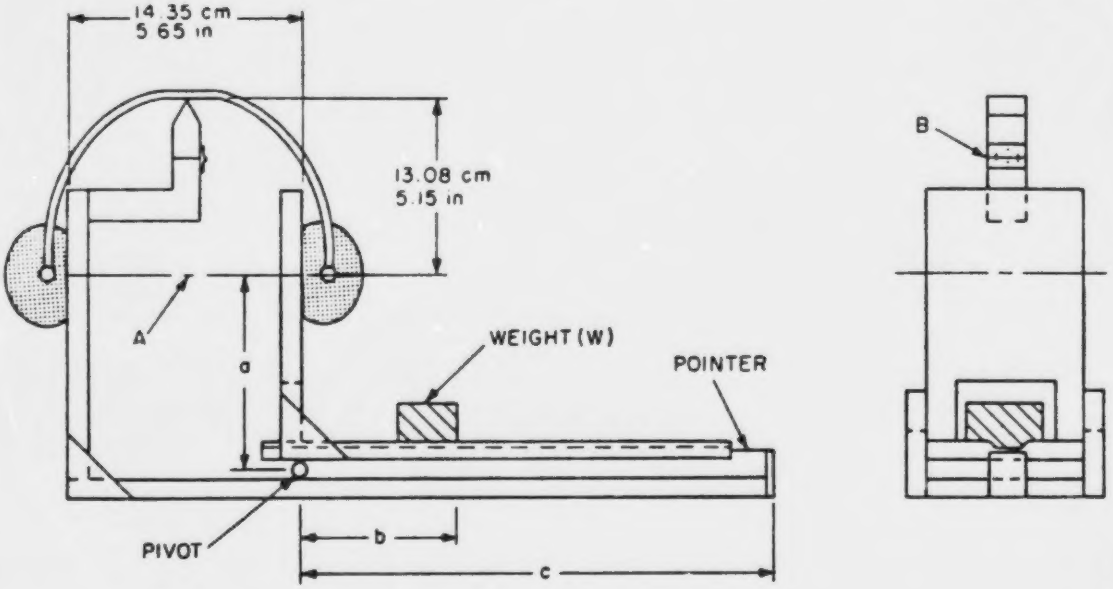
22(cm)
21
20
19
18
17
16
15
14
13
12
DISTANCE

SIGNED

APPENDIX E

Force Measurement Systems

Headband Force Apparatus
(ANSI S 3.19-1974)



Force measurement system.

NOTES:

(1) A: Centerline passes through pivot point of earcup attachment to headband.

(2) B: After correct headband distance is obtained, move out of way for force measurement.

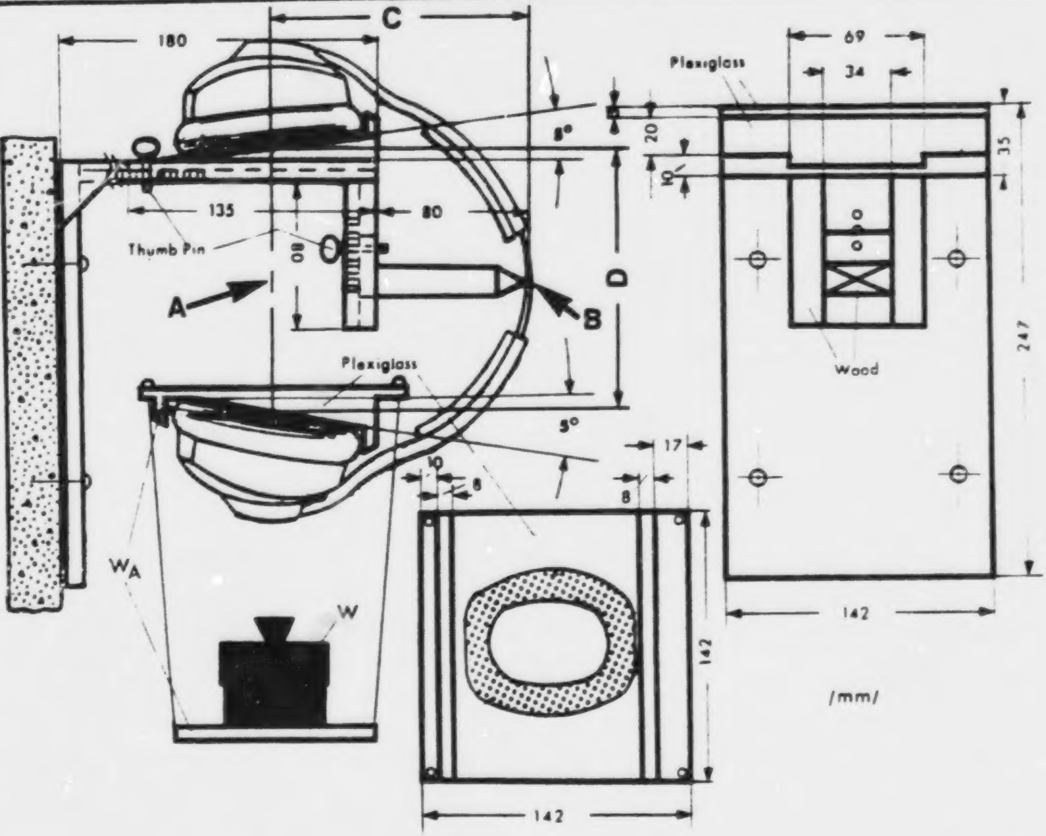
(3) *Construction:* Almost any material can be used providing that the units are made sufficiently rigid. The only critical dimensions are the earcup separation distance (14.35 cm or 5.65 in.) and the headband extension distance (13.08 cm or 5.85 in.). For best results, dimension "a" should be 12.0 cm (4.72 in.) to 15.0 cm (5.90 in.) and dimension "c" should be 30.5 cm (12 in.). A good free-working hinge with a small center pin is satisfactory as the pivot point. Weight is recommended to be about 900 g (about 2 lb).

(4) *Calibration:* With the pointer aligned, the distance between the two faces must be read 14.35 cm ± 0.2 cm. If the construction is such that the weight can be moved over the pivot point, then the zero force location is found by positioning the weight where it just balances. The force (F) at any location at a distance b that the weight has moved from the zero point is found by $F = bW/a$. A scale of grams (pounds) can be marked.

(5) *Operation:* The earmuff to be measured is positioned so that the points of attachment of the headband to the earcups are located at the centerline marks (13.08 cm) and the headband contacts the vertical post. The post is moved away, and the weight is positioned to where the pointers are aligned. The force is read from the scale which converts weight location into grams. When the pointers are aligned, the distance of 14.35 cm is automatically satisfied.

(6) *Accuracy:* The positioning of the earcup must be done with care in order to ensure that the point of attachment of the cup to the headband is the distance a from the pivot point. Practically, this is the largest source of error. With care, the position will be in error less than 0.3 cm for a maximum measurement error of 0.3 cm ÷ 12 cm = 2.6% (2.1% for a = 15 cm). Actual measurements of ten different hearing protectors by three different persons have shown that 95% of the measurements will be within ±50g (about 2 ounces).

Headband Force Apparatus (Elliot Lake Laboratory)


C
180
69
Plexiglass
34
20
10
35
5°
135
80
Thumb Pin
80
D
A
B
Plexiglass
5°
17
10
8
8
Wood
247
W_A
W
142
142
142
/mm/

Clamping force measurement of ear muffs with headband.

NOTES:

1) A: Centreline passes through pivot point of earcup attachment to headband.
   B: After correct head band distance is obtained (operator's head size), move out of the way for force measurement.
   C: Correct operator's head size.
   D: Bizygomatic Diameter (D).

2) Construction: Almost any material can be used: wood, steal, plexiglass, etc.

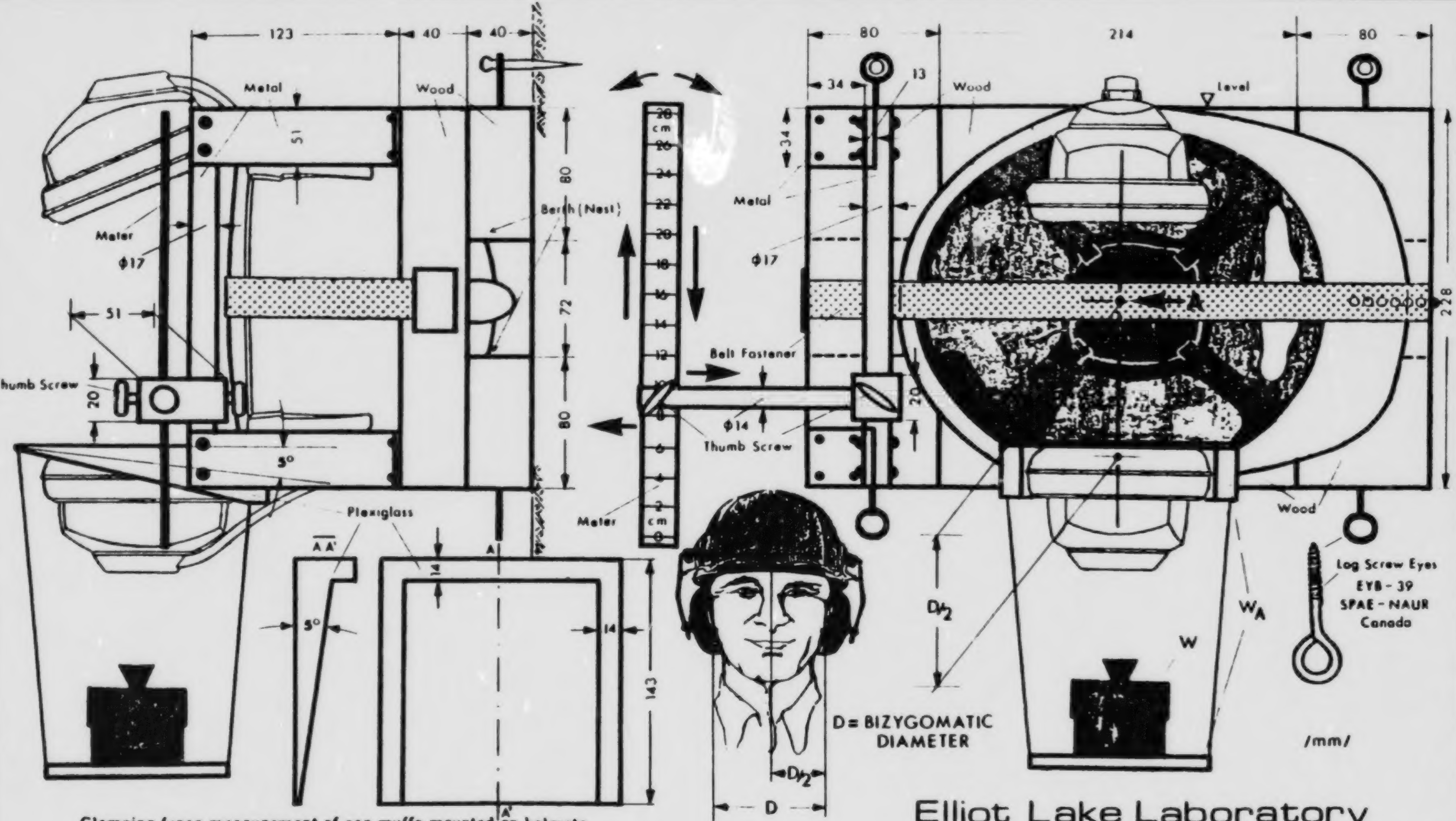
3) Calibration: No calibration. When measuring, the attachment weight must be taken into account. Clamping force (g wt) = $W_A + W$ (where W_A is the attachment weight, and W is the weight).

4) Operation: As shown in Fig. above.

5) Accuracy: ± 10 g.

Elliot Lake Laboratory
CANMET, E.M.R.
By: M.U.Savich

Apparatus for Clamping Force Measurements on Helmet (Elliot Lake Laboratory)


123
40
40
Metal
Wood
51
Meter
ϕ17
51
Thumb Screw
20
5°
80
Berth (Nest)
72
80
Plexiglass
A A'
5°
14
14
143
A
A'
cm
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
cm
Meter
Belt Fastener
ϕ14
Thumb Screw
80
34
13
34
Wood
Metal
ϕ17
20
214
Level
A
228
80
Wood
D/2
W
W_A
Log Screw Eyes
EYB - 39
SPAE - NAUR
Canada
D = BIZYGOMATIC DIAMETER
D/2
D
/mm/

Clamping force measurement of ear muffs mounted on helmets.

Elliot Lake Laboratory

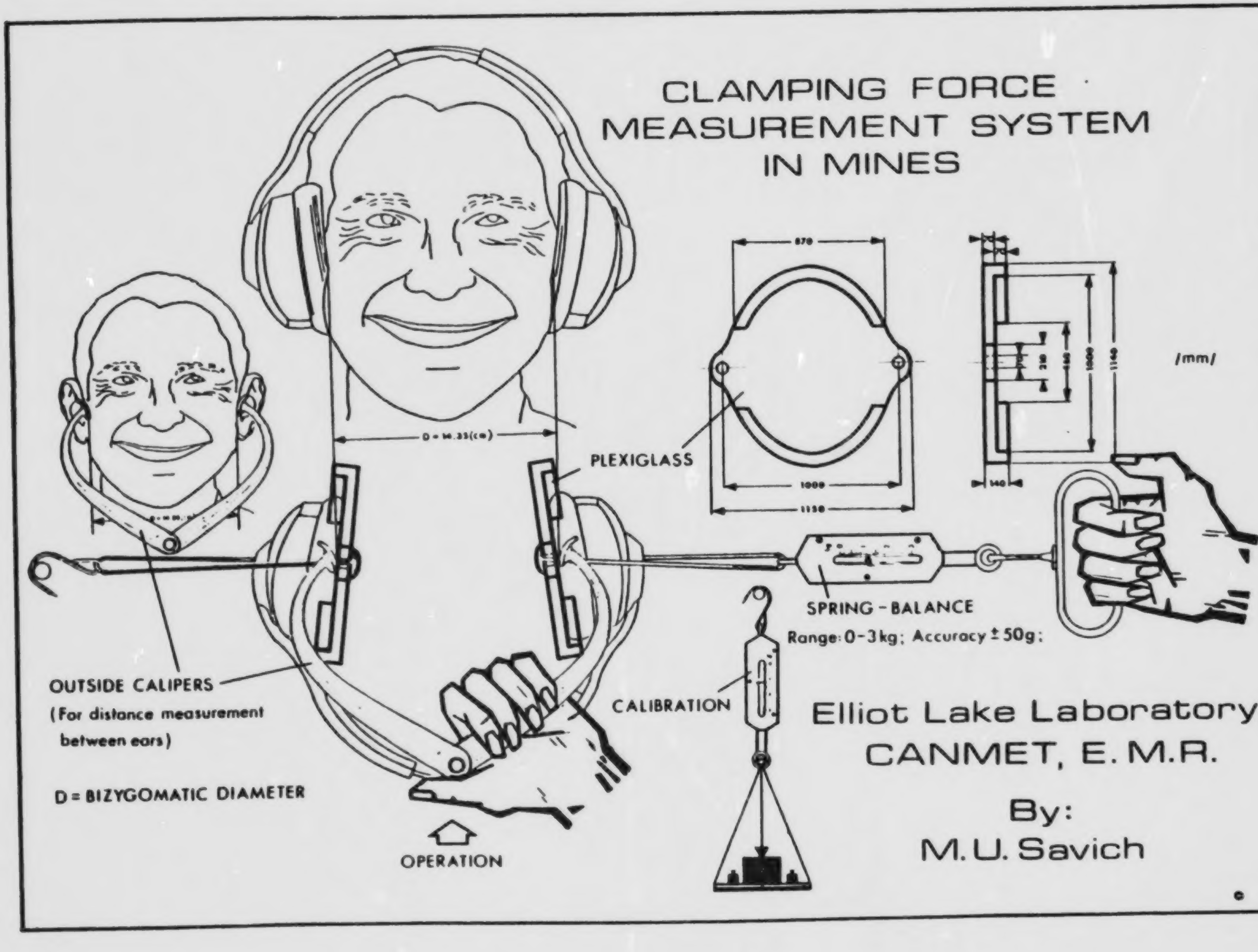
CANMET, E.M.R.

NOTE:

1) A: Centreline passes through pivot point of ear cup attachment to hat (helmet).
2) Construction: Almost any material can be used; wood, steel, plexiglass etc.
3) Calibration: With lag screw eyes both edges of the apparatus are placed horizontally using a level. No calibration with weight.
4) Arrangement: The hat is placed on a berth (nest) lined with rubber and the belt fastener is well tightened.
5) Operation: Measurement should be done for one earcup first. The apparatus is then turned 180°, and measurement is done for the other cup. By this method, assymetry of clamping force can be measured. When measuring, the attachment weight must be taken into account. Clamping force (g wt) = $W_A + W$ (where: W_A is the attachment weight, and W is the weight).
6) Accuracy: ± 10 g.

By: M.U.Savich

Clamping Force Measurement System in Mines



CLAMPING FORCE
MEASUREMENT SYSTEM
IN MINES

D = 14.35(cm)
PLEXIGLASS
870
1000
1150
140
1000
1140
(mm)
SPRING - BALANCE
Range: 0-3kg; Accuracy ± 50g;
CALIBRATION
OUTSIDE CALIPERS
(For distance measurement
between ears)
D = BIZYGOMATIC DIAMETER
OPERATION

Elliot Lake Laboratory,
CANMET, E.M.R.

By:
M.U. Savich

Page 227

Vol. 2 Report 3

78-72 M Savich

Efficiency of ear muffs in mines

1978

EFFICACITÉ DES CASQUES ANTIBRUIT DANS LES MINES

par

M. Savich*

RÉSUMÉ

De nos jours, les casques antibruit font partie du matériel de sécurité utilisé dans les mines canadiennes et, partant, nous avons mené une étude sur l'efficacité de ces casques.

Neuf casques antibruit d'une série de onze ont été essayés dans des conditions uniformes dans des mines. Les trois meilleurs ont été sélectionnés. Les trois doivent être portés derrière la tête (19 dBA à 23,3 dBA). Les raisons d'une mauvaise atténuation sont nombreuses : mauvaise installation des oreillettes sur le casque, port incorrect par les mineurs, mauvaise supervision, formation des mineurs incomplète, etc.

Les résultats de l'étude montrent qu'aucun des casques antibruit essayés ne possède toutes les caractéristiques que l'on devrait retrouver dans un casque idéal.

Étant donné l'atténuation insatisfaisante offerte par le casque antibruit dans des conditions de travail (15 dBA), il devrait être exigé que les travailleurs portent un casque antibruit et des bouchons protecteurs seulement lorsque le niveau de bruit excède 105 dBA (certains auteurs recommandent 110 dBA).

Mots-clés : Bruit, casque antibruit, force de serrage, confort, atténuation, mines.

* Chercheur, Laboratoire d'Elliot Lake, Laboratoires de recherche minière, Centre canadien de la technologie des minéraux et de l'énergie, ministère de l'Énergie, des Mines et des Ressources, Elliot Lake (Ontario).

Voici les clés de la solution au problème :

- le contremaître doit être en mesure d'aider les mineurs à porter correctement le casque protecteur et de faire appliquer le règlement;
- le programme doit être présenté aux mineurs;
- le contact avec les fabricants doit être constant.

Les expériences sur lesquelles sont basées les estimations de la force de serrage, du confort et de l'atténuation sont décrites en détail.

EFFICIENCY OF EAR MUFFS IN MINES

by

M. Savich*

ABSTRACT

Today, in Canadian mines, ear muffs are a part of safety equipment, and because of this, a research study was conducted to investigate the efficiency of ear muffs.

A series of nine ear muffs out of eleven was tested under uniform conditions in mines. Three ear muffs were chosen as the best. All three ear muffs are worn behind the head (19 dBA to 23.3 dBA). Causes of poor attenuation are numerous: bad mounting of ear muffs on helmets, improper wearing by miners, unsatisfactory enforcement by supervisory personnel, incomplete training of miners, etc.

Results of this research have indicated that none of the ear muffs tested in this study contain all of the characteristics desirable in an ideal unit.

Because of unsatisfactory ear muff attenuation in working conditions (15 dBA) it should be a mandatory requirement that workers wear both ear muffs and ear plugs if the noise level is higher than 105 dBA (various literature recommends 110 dBA).

The key to the solution lies in the following:

- the foreman must be capable of helping and controlling miners in their task of wearing ear muffs properly;
- introduce the program to miners; and
- constant contact must be maintained with manufacturers.

Comprehensive descriptions are provided detailing the experiments upon which the estimates of clamping force, comfort and attenuation are based.

Key words: Noise, Ear Muffs, Clamping Force, Comfort, Attenuation, Mines.

* Research Scientist, Elliot Lake Laboratory, Mining Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Elliot Lake, Ontario.

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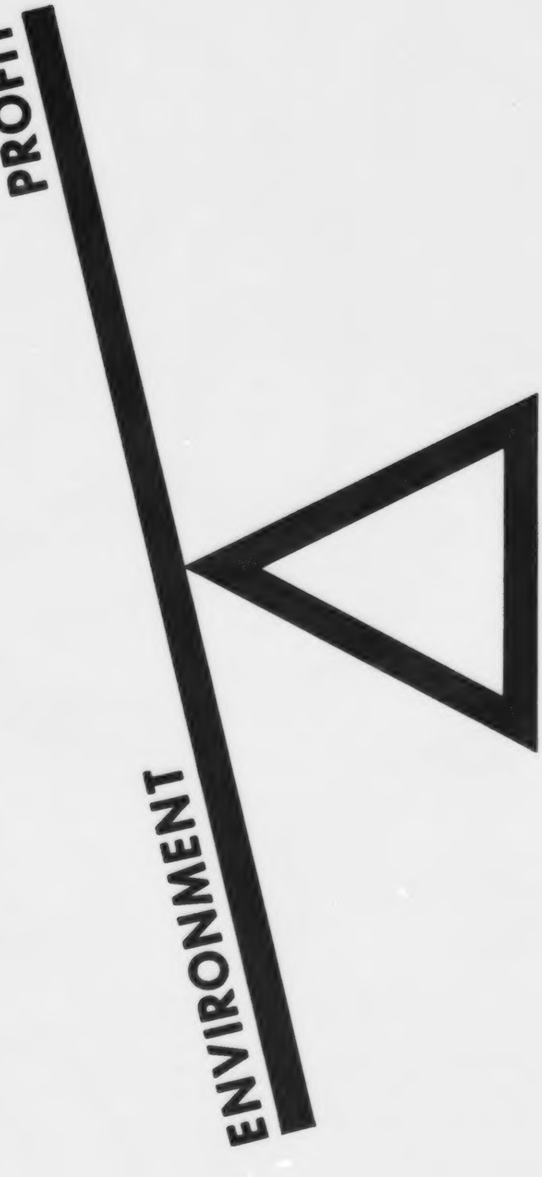
PROFIT
ENVIRONMENT

Vignette

1. INTRODUCTION

Today, problems of noise pollution are widespread, not only in the mining and metallurgical industry, but in many areas of society.

Applications of acoustical theory have become diversified. Because of this, a need has arisen for practical acoustics and noise protection to be synthesized and to offer more practical advice.

Miners exposed to high noise can become temporarily or permanently deafened. Noise can destroy cells in the inner ear. The resulting damage is usually detected by the change in the threshold of hearing. The major benefit of engineering control through hearing protector usage in Canadian mines is that a number of miners will be protected from a hearing impairment. Because of this, a study was undertaken to measure ear muff attenuation in mines.

2. GENERAL CONSIDERATIONS

The benefits of reduced noise in mines fall under two categories:

1. The benefits of reduced risk of hearing loss, and
2. The benefits relating to more pleasant working conditions.

Much of the recent information about the dangers of the Canadian mining industry came to light during the Ontario Royal Commission's investigation into the health and safety of workers in mines (1). Following the Commission's recommendations, the Ontario Government brought in Bill 139, which gives workers the right to refuse to work under unsafe conditions. Noise pollution has come to be recognized as a hazardous problem in mines and mills. Surveys of all Ontario industries indicate that the compensation payments awarded in 1976 for noise deafness were around 9 million dollars (Fig. 1) (2).

2.1. Preventive and Protective Measures

There are three basic elements which should be kept in mind in noise and vibration control: a source, a path, and a receiver. The criteria and

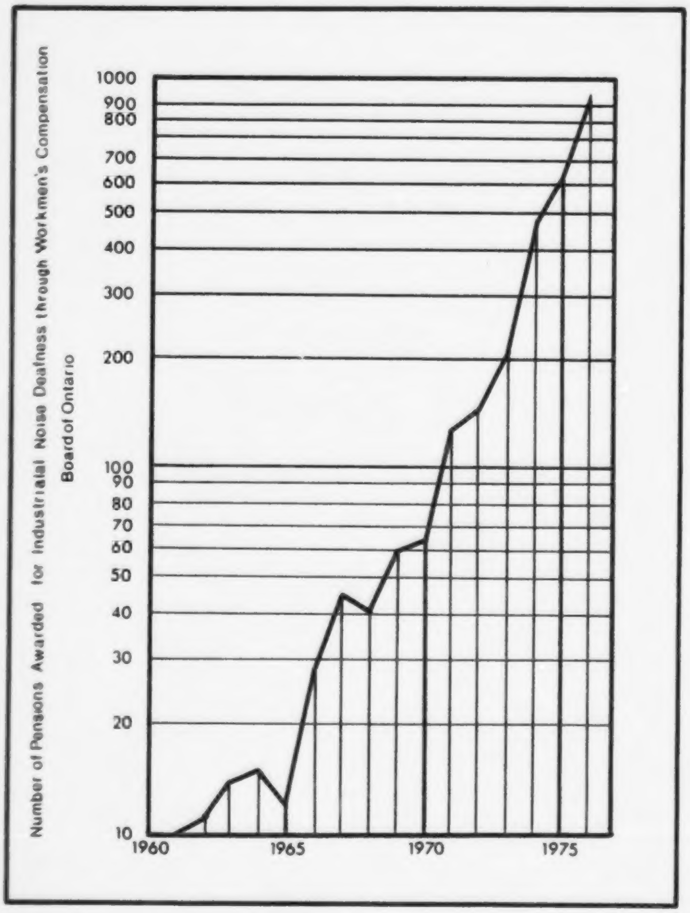

Fig. 1: Noise deafness pensions awarded in Ontario between 1961 and 1976. Note: The average award in 1976 was $8,500 (2)

Vignette

exposure limits should be established, supplemented and revised regularly in the light of current knowledge and data. The prevention of occupational hazards in the working environment due to noise and vibration should be kept within limits (3) by:

a) technical measures;

b) supplementary administrative measures, where the technical measures alone do not provide sufficient protection.

Where such measures do not make it possible to bring noise and vibration within the limit:

a) the employer should supply workers with suitable personal protective equipment and should maintain that equipment; and

b) the employer should provide appropriate training in the use and maintenance of such equipment, so that workers can comply with relevant instructions.

The codes or regulations should provide for all persons concerned to be adequately:

a) informed of potential occupational hazards in the working environment due to noise and vibration; and

b) instructed in the measures available for the prevention and control of, and protection against, those hazards.

Measures should be taken to promote research in the field of prevention and control of hazards in the working environment due to noise and vibration. The purpose of this investigation was to systematically assess the noise reduction of ear muffs and to find the best methods possible to control the hazards.

2.2. Existing and Proposed Noise Standards

The noise exposures permitted by the existing OSHA* standard are given in Table 1. When the noise consists of different levels throughout the day, their combined effect is considered as follows:

$$\Sigma C/T = (C_A/8 + C_B/6 + C_C/4 + C_D/3 + C_E/2 + \ldots + C_J/0.25) \quad \text{(Eq. 1)}$$

where $\Sigma C/T \leq 1$ is the OSHA Mixed Exposure Index, and C_A is the total time the noise level is in band A, C_B is the total time the noise level is in band B, etc.

TABLE 1

Noise Exposure Limits for a Normal 8-Hour Working Day[+]

Band	Noise Level (dBA)	Maximum Exposure (h)
A	90	8
B	92	6
C	95	4
D	97	3
E	100	2
F	102	1.5
G	105	1
H	110	0.5
J	115	0.25
	Above 115	None

[+] U.S. Code of Federal Regulations, Title 29, Section 1910.95.

The criteria are based on measurements of the equivalent continuous noise level, L_{eq}: provided the noise is not of an "impulsive" nature (Appendix A-1). Limits are based on tests showing that, for every halving of the duration of exposure, the intensity of exposure can be increased 5 dBA without an increase in the risk of noise-induced hearing losses. The A-weighted reading is used to estimate the probability of hearing damage in industry (Appendix A-2).

---

* The Occupational Safety and Health Act (U.S.A.).

The National Institute for Occupational Safety and Health (NIOSH) issued a criteria document which called for the eight-hour exposure to be limited to 85 dBA, the four-hour exposure to 90 dBA,etc. (4). NIOSH recommended an 85-decibel standard to reduce the chance of workers' hearing loss.

2. 3. The Costs of the OSHA and NIOSH Noise Proposals

OSHA commissioned an economic impact study to estimate the cost with the 90-decibel standard (which was not being completely enforced) and the 85-decibel standard. An economic impact study shows U.S. industry's cost of meeting a 90-decibel noise standard would be 13.5- billion U.S. dollars and to comply with the 85-decibel noise standard in five years would require an additional 8-billion U.S. dollars (5). The estimate is based on achieving compliance through engineering alone; with an estimated 155-million U.S. dollars in added cost required annually to maintain monitoring programs and 86-million U.S. dollars for audiometric testing.

To answer the question of how much is needed from Canadian industry to implement and meet 90-decibel and 85-decibel noise standards, a rough estimate can be made using OSHA's U.S. estimates.

Since the economic structures in the U.S. and Canada are similar, the estimate was made on the basis of the 1976 census:

	Population
Canada	23, 143, 000
United States	215, 118, 000

Estimation* shows that Canadian industry's cost of meeting the 90-decibel noise standard would be 1.7 billion Canadian dollars and 1 billion would be needed to comply with the 85-decibel noise standard. An additional cost of 19-million Canadian dollars would be required annually for permanent monitoring and 10.6-million dollars would be needed annually for audiometric testing.

A significant amount of money would have to come from mines, mills and metallurgical plants. In the calculations the inflationary rate of U.S. dollars, which amounts to at least 10% yearly, was not taken into account.

2.4. Working Environment in Canadian Mines

For a better understanding of the noise environment and noise protection in Canadian mines an analysis was made:

1. Noise exposure limits specified in Provincial Government regulations are applied in the mining environment. Many machines and installations have noise levels much above the permitted exposure limit and significant reductions have not yet been obtained.
2. A competent authority in the Provincial Government prescribes the frequency, band number for acoustical measurements, and other monitoring conditions for noise in the mining environment. This monitoring is to be carried out by employers even though some mine managements are not always effective in carrying out the task.
3. To satisfy regulations, noise recognized as harmful should be minimized by placing mufflers or exhaust hoses on machinery (Fig. 2). Methods of

---

*Mid-Market rates in Canadian Funds, April 10, 1978. Prepared by the Bank of Nova Scotia.

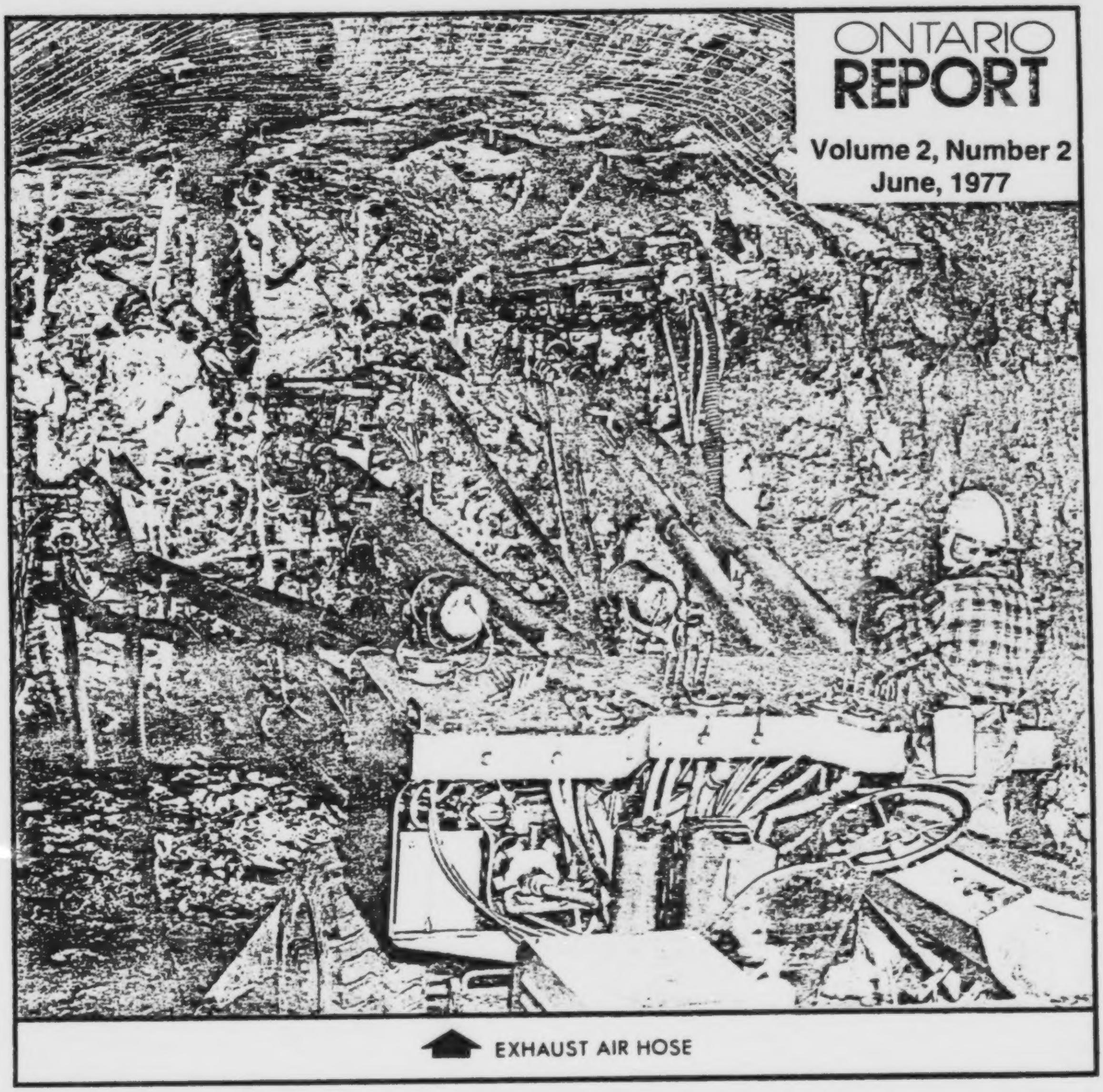
ONTARIO
REPORT
Volume 2, Number 2
June, 1977
EXHAUST AIR HOSE

Fig. 2: A total environment in Canadian mines: roof bolting, good lighting, silencing of exhaust air with hose (~115 dBA), and use of personal protective equipment (ear muffs, glasses, etc.).

meeting regulations differ from province to province and mine to mine.

4. The manufacturers have started to make machines and installations that meet noise requirements.

5. Provincial regulations permit the use of personal protective equipment

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(ear plugs and ear muffs) to meet noise control requirements only if reduction by technical or administrative means is not technically feasible.

6. In all mines, audiometric tests are required to be carried out by a competent authority:

   a) a pre-assignment examination, and

   b) at suitable periodic intervals.

7. Federal and Provincial Governments promote, assist and stimulate research in the field of prevention and control of noise hazards in the mining environment.

8. Employers' and miners' organizations take action to carry out training and information programs to control noise hazards in the mining environment.

Until technical advances and more stringent regulations are made, along with a larger staff of mine inspectors to enforce them, noise will continue to be a health hazard in the Canadian mining industry. Constant, voluntary use of personal protective equipment, (such as ear plugs and muffs) in all Canadian mines, will guard miners from the threat of hearing loss. Because of this, a new effort has been made to obtain an analysis of ear muffs to improve their application under working conditions.

3. EAR MUFF ATTENUATION TESTS IN MINES

A study was undertaken to measure ear muff attenuation in mines. A series of nine ear muffs was tested under uniform conditions in mines.

3.1. Objective of the Study

The only certain means for evaluating the efficiency of the hearing protection program, equipment, training and supervision, is to measure, periodically, the hearing thresholds of all miners exposed to noise (6). However, this method does not detect problems until some hearing loss has occurred.

Because of this a new method is being developed in the Elliot Lake Laboratory. This method will provide an assessment of attenuation efficiencies of ear muffs in use.

3.2. Attenuation Characteristics of Ear Muffs

Attenuation data on ear muffs is given in Table 2.

No. 7 and No. 8 ear muffs, model G and model H were designed to be worn with the suspension over the head, thus making it impossible to wear a helmet at the same time. Because of this they could not be tested, and we had to rely solely on theoretical attenuation values.

3.3. Experimental Method

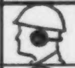
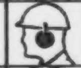
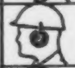
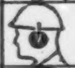
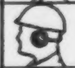
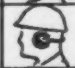
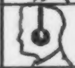
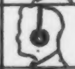
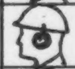
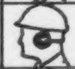
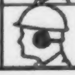
The Noise Dosimeter Vest's technical solution provides for the determination of the noise exposure index and the attenuation of ear muffs (Fig. 3). It does so under the most difficult working conditions (i.e., single platform (giraffe), the load-haul-dump (LHD) vehicle, etc.).

These tests require only two dosimeters and a stop watch. The dosimeters have small microphones and very accurate short time readings of the noise exposure index. Ear clips should be coloured differently according to intended use inside or outside an ear muff.

Also, a pocket-sized computer designed for sound amplitude analysis should be utilized (dBA, L_{eq}, L_{max} and time duration of the sampling period).

TABLE 2

Attenuation Characteristics of Ear Muffs Acquired for Testing

No.	Ear Muff	Band	Characteristic	Attenuation (dB)*								
				Frequency in Hertz								
				125	250	500	1k	2k	3k	4k	6k	8k
1	A		Measured	9.7	16.1	24.9	33.9	34.1	36.0	41.0	33.8	31.5
			Std. Dev.	3.2	2.5	2.8	5.1	2.9	5.6	5.7	6.6	5.9
2	B		Measured	5	13	22	31	31	41	36	28	21
			Std. Dev.	-	-	-	-	-	-	-	-	-
3	C		Measured	10	16	30	34	37	41	45	39	34
			Std. Dev.	-	-	-	-	-	-	-	-	-
4	D		Measured	11.5	16.5	26.5	36.5	38	38.5	44.5	39.5	-
			Std. Dev.	-	-	-	-	-	-	-	-	-
5	E		Measured	13.4	17.3	28.6	41.8	40.7	45.2	42.7	32.6	29.3
			Std. Dev.	3.3	3.9	3.0	3.4	5.6	4.6	5.3	4.1	4.7
6	F		Measured	17	18	29	36	38	44	44	43	43
			Std. Dev.	2.6	2.6	3.1	3.2	4.1	7.2	4.6	4.7	5.7
7	G		Measured	18	23	33	44	44	47	45	42	39
			Std. Dev.	-	-	-	-	-	-	-	-	-
8	H		Measured	18	23	33	44	44	47	45	42	39
			Std. Dev.	-	-	-	-	-	-	-	-	-
9	I		Measured	12	17	30	35	35	36	37	32	30
			Std. Dev.	2.5	3.0	4.6	5.6	4.5	4.3	4.2	4.1	2.9
10	J		Measured	10	17	28	37	36	44	39	32	30
			Std. Dev.	2.0	2.6	4.3	5.4	4.5	5.6	3.8	5.4	4.9
11	K		Measured	15	17	26	43	36	38	38	33	34
			Std. Dev.	5.2	3.9	8.8	3.6	4.9	6.6	6.8	1.3	5.3
Σ	Arithmetic Mean of all Ear Muffs			12.16	17.09	27.8	37.22	36.98	41.07	41.22	35.49	33.53
	Std. Dev.			3.86	2.47	3.09	4.31	3.58	3.9	3.49	5.0	7.36

* Attenuation characteristic measured in accordance with American National Standard Specification Z. 24. 22-1957 (from Factory Data).

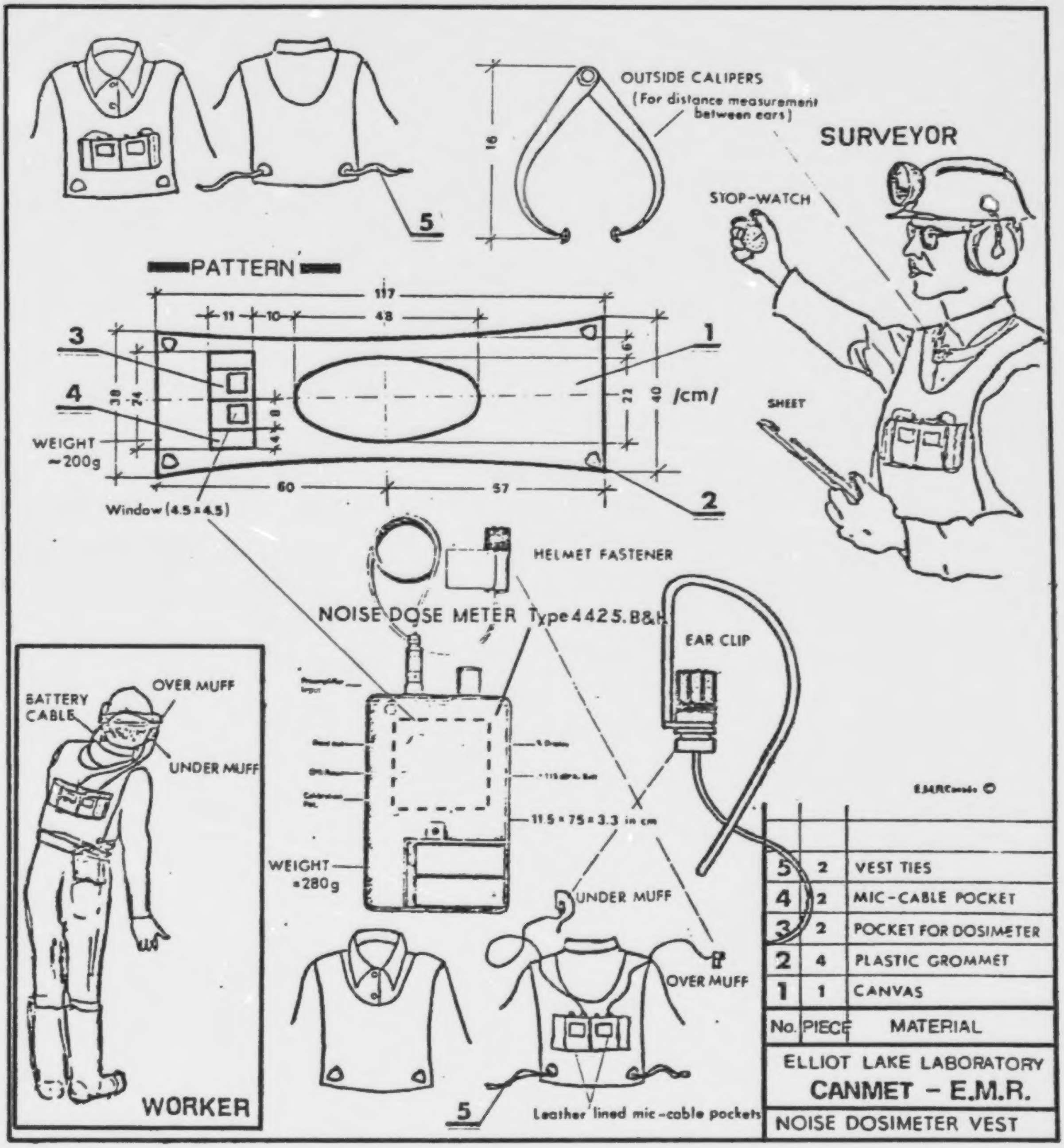

OUTSIDE CALIPERS
(For distance measurement between ears)
16
5
SURVEYOR
STOP-WATCH
SHEET
PATTERN
117
11
10
48
3
1
4
38
24
8
4
6
22
40
/cm/
WEIGHT ~200g
60
57
2
Window (4.5×4.5)
HELMET FASTENER
NOISE DOSE METER Type 4425.B&K
EAR CLIP
11.5×75×3.3 in cm
WEIGHT ≈280g
BATTERY CABLE
OVER MUFF
UNDER MUFF
WORKER
UNDER MUFF
OVER MUFF
5
Leather lined mic-cable pockets
E.M.R.Canada ©
5 2 VEST TIES
4 2 MIC-CABLE POCKET
3 2 POCKET FOR DOSIMETER
2 4 PLASTIC GROMMET
1 1 CANVAS
No. PIECE MATERIAL
ELLIOT LAKE LABORATORY
CANMET – E.M.R.
NOISE DOSIMETER VEST

Fig. 3: The noise dosimeter vest in use during ear muff attenuation measurements.

The surveyor must measure the distance between the bony structures just forward of the ears (bizygomatic diameter) using an outside caliper. The measurement of this distance is entered on the right hand side of the Ear Muff Noise Attenuation Survey Form (Appendices B-1, B-2 and B-3). On the basis of bizygomatic diameter measurements, the clamping force can be evaluated. For the immediate measurement of clamping force in mines, an apparatus was designed in the Elliot Lake Laboratory (Appendix C-1). The full procedure for measurement and evaluation of the noise exposure index and ear muff noise reduction can be seen in the Ear Muff Noise Attenuation Survey Forms. Evaluations are done on the spot and the worker is immediately informed about the noise exposure index level and ear muff attenuation data. If the attenuation is unsatisfactory, the cause will have to be investigated. This investigation may be done on the spot in some cases, or in the laboratory. Results are filed in the office.

3.4. Participants

In this study one man at each of three working sites was chosen:

1. Jumbo (Three Drills) Operator;
2. Drill Hydrofore Operator, and
3. Jaw Crusher Operator.

Of particular importance were the following items:

- The miner is informed of the test's objective;
- The miner is asked to adjust his own ear muffs to his particular liking, and to make qualitative evaluations of comfort before and after the test.
- If a miner wishes to withdraw at any time and for any reason, he may do so.

It was explained that all testing would be conducted under the full support of miners and supervisory personnel.

3.5. Results

The results of the study indicate poor attenuation of ear muffs in underground mining conditions. As a result of analyzing the data obtained, three major findings are presented below.

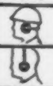
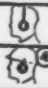
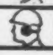
The clamping forces were calculated in the laboratory on the basis of measured bizygomatic diameters (Appendices C-2 and C-3).

Jumbo (Three Drills) Operator: While working the jumbo operator used only ear plugs. The miner was of the opinion that his ear muffs were inefficient and wore them only because regulations required it. The ear muff was No. 6, model F, with hat mounting, that could not properly cover the ears. On the basis of obtained results, it is evident that the noise levels are high (115 dBA) and that the ear muffs supplied do not offer adequate protection (Table 3). The test results show that this jumbo operator had very ill-fitting hat-mounted ear muffs. The ear muffs with adequate attenuation were No. 1, 2, 5 and 10. In all cases, one of the factors contributing to the jumbo operator's problem was his extremely small head size. The jumbo operator judged ear muffs which are worn behind the head (Nos. 6 and 11) as poor providers of comfort. Also, such ear muffs have poor attenuation (Table 3).

Drill Hydrofore Operator: Hydraulic drills are used increasingly on jumbo machines, replacing the heavy pneumatic rock drills. There are many reasons why the hydraulic percussion rock drill is better, e.g., faster

TABLE 3

Attenuation of Ear Muffs at the Jumbo Operator's Station

No.	Ear Muff	Band	Comfort +	(cm)	JUMBO (THREE DRILLS) OPERATOR									
					Clamping Force (g wt)			Attenuation (dBA)			L_{eq} (dBA)			
					✿ L.S.	✿ R.S.	✿ B.S.	L.S.	R.S.	Ave.	L.S.	R.S.	Ave.	
1	A		⬙	12.8	-	-	430	20.8	14.2	18.65	115.5	115.1	115.3	
2	B	①	⬙	12.8	530	230	760	14.4	17.9	16.49	115	114.8	114.9	
3	C	②	◆	12.8	580	630	1210	11.3	11.7	11.5	114.1	113.8	113.95	
4	D	③	⬙	12.8	930	1030	1960	12.3	14.6	13.6	116	112.9	114.45	
5	E		⬙	12.8	-	-	1830	28	20.2	25.66	117	117.6	117.3	
6	F		◆	12.8	-	-	1080	9.6	7.2	8.56	114.4	116.4	115.4	} Mine Standard in Use
7	G		-	12.8	-	-	1130	-	-	-	-	-	-	
8	H		-	12.8	-	-	1030	-	-	-	-	-	-	
9	I	④	◆	12.8	630	730	1360	4.8	0.6	3.19	115	112.1	113.55	
10	J		◇	12.8	-	-	1230	~25	~25	~25	109.7	116.2	112.95	
11	K		◆	12.8	-	-	830	11.5	12	11.76	114.3	115.8	115.05	
	Mean		-	12.8	-	-	1168	-	-	-	114.55	114.97	114.76	
	Std. Dev.		-	-	-	-	443	-	-	-	2.04	1.77	1.27	
	$\overline{SPL}^x$		-	-	-	-	-	-	-	-	114.9	115.3	115.1	

① Tested while mounted on helmet; 905 ERB Plastics, Inc., Woodstock CA, 905.

② Tested while mounted on helmet; Classe C, CSA Standard Z94.1.

③ Tested while mounted on helmet; Safety Supply Co., Rain-Guard, Safe-T-Cap, CSA Standard Z.94.1.

④ Tested while mounted on helmet; Hard Boiled, E.D. Bollard Co., S.F., U.S.A.

NOTE: + Evaluation ◆ Satisfactory (1)
⬙ Good (2)
◇ Very Good (3)

✿ L.S. - Left Side; R.S. - Right Side; B.S. - Both Sides

x Average $\overline{SPL} = 10 \log \frac{1}{n} (\text{antilog} \frac{SPL_1}{10} + \text{antilog} \frac{SPL_2}{10} + \ldots + \frac{SPL_n}{10})$

penetration, longer parts life, better drilling control, improved efficiency, no fog, and lower noise levels (one boom creates noise levels of only 105 dBA) etc. (7). A hydrofore drill (hydraulic-electric fan) has no air exhaust noise and thus produces low noise levels at low frequencies. Because the attenuation of ear muffs is better at high frequencies, it should be expected that their efficiencies would be very high.

Test results demonstrate that better attenuations are obtained by ear muffs Nos. 5, 6 and 10 (Table 4). All three muffs were worn behind the head. The remaining ear muffs did not provide satisfactory attenuations.

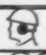
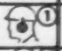
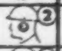
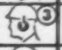
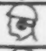
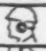
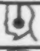
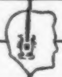
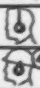
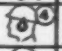
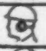
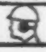
Jaw Crusher Operator: Generally speaking, ear muffs should be used where the ambient sound levels exceed 105 dBA. Below this value ear plugs give good protection. Because ear muffs are practical for intermittent noise (and because infection can result from the use of ear plugs), usually only ear muffs are used to protect from lower noise levels in all areas of mines. Test results from eight ear muffs show sufficient attenuation to 90 dBA and below (Table 5). Only ear muff No. 9 has a very low attenuation (8.3 dBA). Once again, extremely good attenuation is provided by three muffs: No. 5 (18.8 dBA), No. 6 (23.8 dBA) and No. 10 (23.1 dBA).

3.6. Clamping Force and Comfort

On the average, ear muffs have poor attenuation (~15 dBA). Thus ear muffs and ear plugs should be used in tandem. The efficiency of an ear muff is determined by its clamping force and its fit over the ear. If the clamping force is decreased, attenuation also decreases. Clamping force will vary in each case because of different head sizes (Tables 3, 4, and 5).

TABLE 4

Attenuation of Ear Muffs at the Drill Hydrofore Operator's Station

No.	Ear Muff	Band	Comfort+	(cm)	DRILL HYDROFORE OPERATOR									
					Clamping Force (g wt)			Attenuation (dBA)			L_{eq} (dBA)			
					✡L.S.	✡R.S.	✡B.S.	L.S.	R.S.	Ave.	L.S.	R.S.	Ave.	
1	A		◆	13.8	-	-	580	13.5	11.5	12.6	103.8	106.2	105	
2	B	 ①	◇	13.8	680	380	1060	11.4	12.6	12.04	104.3	107.1	105.7	
3	C	 ②	◆	13.8	630	680	1310	10.3	4.2	8.25	106.6	106.9	106.7	
4	D	 ③	◇	13.8	1030	1080	2110	11.5	9.1	10.46	104.8	104.6	104.7	
5	E		◇	13.8	-	-	2080	27.2	21.7	25.26	104.2	108.7	106.4	
6	F		⬙	13.8	-	-	1230	25.6	23.4	24.64	104.3	102.3	103.3	
7	G		-	13.8	-	-	1230	-	-	-	 -	-	-	Mine Standard in use
8	H		-	13.8	-	-	1130	-	-	-	-	-	-	
9	I	 ④	⬙	13.8	680	880	1560	6.4	5.1	5.80	104.9	103.3	104.1	
10	J		⬙	13.8	-	-	1380	15.8	19.8	18.24	102.8	103.3	103.0	
11	K		◇	13.8	-	-	930	10.4	9.5	9.97	104.9	103.9	104.4	
	Mean		-	13.8	-	-	1327	-	-	-	104.5	105.1	104.8	
	Std. Dev.		-	-	-	-	456	-	-	-	1.03	2.17	1.29	
	$\overline{SPL}^x$		-	-	-	-	-	-	-	-	104.6	105.6	105.1	

① Tested while mounted on helmet; 905 ERB Plastics, Inc., Woodstock CA, 905.

② Tested while mounted on helmet; Classe C, CSA Standard Z.94.1.

③ Tested while mounted on helmet; Safety Supply Company, Rain-Guard, Safe-T-Cap, CSA Standard Z 94.1.

④ Tested while mounted on helmet; Hard Boiled, E.D. Bollard Co., S.F., U.S.A.

NOTE: + Evaluation
◆ Satisfactory (1)
⬙ Good (2)
◇ Very Good (3)

✡ L.S. - Left Side; R.S. - Right Side; B.S. - Both Sides.

x Average $\overline{SPL} = 10 \log \frac{1}{n} (\text{antilog} \frac{SPL_1}{10} + \text{antilog} \frac{SPL_2}{10} + ---- + \frac{SPL_n}{10})$

TABLE 5

Attenuation of Ear Muffs at the Jaw Crusher Operator's Station

No.	Ear Muff	Band	Comfort +		JAW CRUSHER OPERATOR									
					Clamping Force (g wt)			Attenuation (dBA)			L_{eq} (dBA)			
					✡ L.S.	✡ R.S.	✡ B.S.	L.S.	R.S.	Ave.	L.S.	R.S.	Ave.	
1	A		◇	13.5	-	-	580	15	15	15	101.7	101.3	101.5	
2	B	①	◆	13.5	580	330	910	4.7	13.8	11.29	97.4	100.9	99.15	
3	C	②	◆	13.5	630	680	1310	9.8	10.8	10.33	100.4	103.6	102	
4	D	③	◆	13.5	980	1080	2060	14.3	6.8	12	102.5	101.8	102.15	
5	E		⬙	13.5	-	-	1980	18.4	19.2	18.82	102.2	101.3	101.75	
6	F		⬙	13.5	-	-	1180	18	26.2	23.8	99.7	100.9	100.3	} Mine Standard in Use
7	G		-	13.5	-	-	1180	-	-	-	-	-	-	
8	H		-	13.5	-	-	1080	-	-	-	-	-	-	
9	I	④	◆	13.5	680	830	1510	7.4	9.0	8.27	100.3	103.7	102	
10	J		◇	13.5	-	-	1330	22.8	23.4	23.11	95.9	98.6	97.25	
11	K		⬙	13.5	-	-	880	17.8	13.4	16	100	103.4	101.7	
	Mean		-	13.5	-	-	1273	-	-	-	100	101.7	100.87	
	Std. Dev.		-	-	-	-	447	-	-	-	2.18	1.65	1.68	
	$\overline{SPL}^{x}$		-	-	-	-	-	-	-	-	100.44	101.98	101.28	

① Tested while mounted on helmet; 905 ERB Plastics, Inc., Woodstock CA, 905.

② Tested while mounted on helmet; Classe C, CSA Standard Z 94.1.

③ Tested while mounted on helmet; Safety Supply Co., Rain-Guard, Safe-T-Cap, CSA Standard Z 94.1.

④ Tested while mounted on helmet; Hard Boiled, E.D. Bollard Co., S.F., U.S.A.

NOTE: + Evaluation
◆ Satisfactory (1)
⬙ Good (2)
◇ Very Good (3)

✡ L.S. - Left Side; R.S. - Right Side; B.S. - Both Sides

x Average $\overline{SPL} = 10 \log \frac{1}{n} (\text{antilog} \frac{SPL_1}{10} + \text{antilog} \frac{SPL_2}{10} + \dots + \frac{SPL_n}{10})$

A good fit over the ear is an important factor for noise attenuation, and it is inter-related with comfort. From the tests performed it is evident that comfort and attenuation affect one another (Table 6).

Characteristically, ear muffs mounted on the hat and worn behind the head have different comfort evaluations and different attenuation results (Nos. 4, 5, 9 and 10). In all cases, hats cause these discrepancies. There are other numerous causes: poor mounting due to insufficient instructions, varying head dimensions and ear heights, improper fitting, interference by hair or eye-glasses, improper wearing of ear muffs, etc. Because of this the value of a measured attenuation in use does not equal the value of an approximate method for calculating noise reduction and theoretical attenuation (noise reduction-computer programs) (Table 6) (8) (9) (10). Results of the theoretical noise reduction can be easily compared with EPA's* proposed labeling of hearing protection products (11).

Clamping force studies were made with eleven and ten ear muffs (Table 7).

Ear Muffs	Mean Clamping Force $\overline{X}$ (g wt)	Number of Observations n	Standard Deviation σ (g wt)
11	1256	33	440
10	1264	30	461

Because the number of observations is sufficiently large (say, $n \geq 30$), a close estimate of the standard deviation σ_d is possible. The significance of the difference of means ($\overline{X}$) is measured by the ratio of the difference to its standard deviation (S), namely (12):

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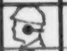
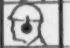
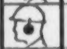
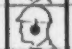
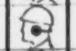
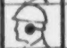
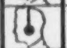
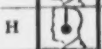
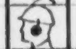
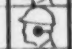
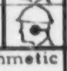
* The Environmental Protection Agency, U.S.A.

TABLE 6

Summary of Comfort and Measured Attenuation, Approximate Attenuations and Theoretical Attenuation

No.	Ear Muff	Band	Comfort$^+$				Noise Reduction - dBA																				
							Measured*				Approximate Methods												Theoretical Method			
			Jumbo Operatr	Hydro Operatr	Crusher Operatr	Σ	Jumbo Operatr	Hydro Operatr	Crusher Operatr	Σ/3	Jumbo Operator				Hydrofore Operator				Crusher Operator				Jumbo Operatr	Hydro Operatr	Crusher Operatr	Σ/3
											1^+	2^+	3^+	Σ/3	1^+	2^+	3^+	Σ/3	1^+	2^+	3^+	Σ/3				
1	A		⬙	◆	◇	6	18.6	12.6	15	15.4	20.38	16.78	17.28	18.15	22.71	18.71	17.28	19.57	21.16	17.65	17.28	18.70	26.9	28.8	27.7	27.8
2	B		⬙	◇	◆	6	16.5	12	11.3	13.3	-	13.08	13.50	13.29	-	15.52	13.50	14.51	-	14.06	13.50	13.78	23.1	25.5	24.1	24.2
3	C		◆	◆	◆	3	11.5	8	10.3	9.9	-	17.73	18.35	18.04	-	19.56	18.35	18.95	-	18.54	18.35	18.44	27.8	29.6	28.6	28.7
4	D		⬙	◇	◆	6	13.6	10.5	12	12	-	18.20	18.87	18.53	-	19.90	18.87	19.38	-	19.02	18.87	18.94	28.2	29.9	29	29
5	E		⬙	◇	◇	7	25.7	25.3	18.8	23.3	21.95	19.22	19.85	20.34	23.21	20.89	19.85	21.32	22.97	20.45	19.85	21.09	29.4	30.9	30.4	30.2
6	F		◆	⬙	⬙	5	8.6	24.6	23.8	19	24.67	20.62	21.17	22.15	25.43	21.38	21.17	22.66	25.35	21.33	21.17	22.62	30.6	31.4	31.3	31.1
7	G		-	-	-	-	-	-	-	-	-	(25.07)	(25.66)	(25.36)	-	(27.04)	(25.66)	(26.35)	-	(25.91)	(25.66)	(25.78)	(34.6)	(36.3)	(35.4)	(35.4)
8	H		-	-	-	-	-	-	-	-	-	(25.07)	(25.66)	(25.36)	-	(27.04)	(25.66)	(26.35)	-	(25.91)	(25.66)	(25.78)	(34.6)	(36.3)	(35.4)	(35.4)
9	I		◆	⬙	◆	4	3.2	5.8	8.3	5.8	24.81	18.48	18.94	20.74	24.73	19.9	18.94	21.19	25	19.29	18.94	21.08	28.5	29.9	29.3	29.2
10	J		◇	⬙	◇	8	25	18.2	23.1	22.1	21.67	18.30	18.44	19.47	23.19	20.11	18.44	20.58	22.62	18.85	18.44	19.97	27.9	30.1	28.9	29
11	K		◆	◇	⬙	6	1. 8	10	16	12.6	22.26	19.02	19.49	20.26	23.81	20.09	19.49	21.13	22.76	19.74	19.49	20.66	29	30.2	29.8	29.7
Σ-(7+8)	Arithmetic Mean						14.94	14.11	15.40	14.82	22.62	17.94	18.43	19.00	23.85	19.56	18.43	19.92	23.31	18.77	18.43	19.48	27.93	29.59	28.79	28.77
	Std. Dev.						7.38	7.03	5.55	5.74	1.76	2.11	2.14	2.53	1.04	1.69	2.14	2.33	1.58	2.07	2.14	2.53	2.10	1.70	2.04	1.95

Note:

* In Mines

+ Method

+ Evaluation: ◆ Satisfactory (1)

⬙ Good (2)

◇ Very Good (3)

* Appendix A-3, Computer Program

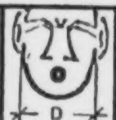
Noise Surveys in Mines

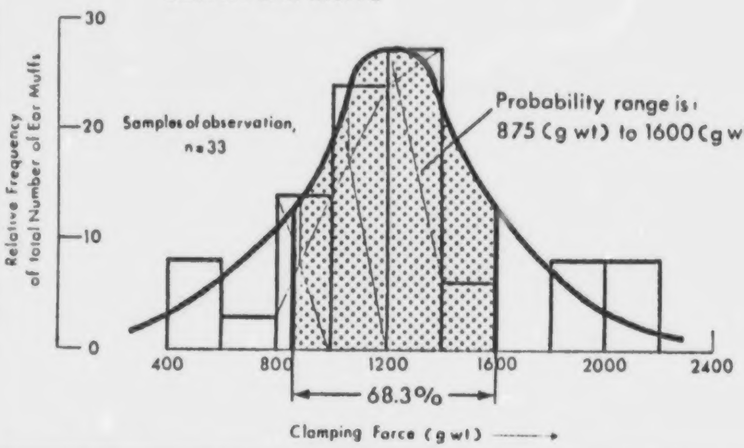
Measured at the Operator's Ears	Frequency (Hz)									dBA
	31.5	63	125	250	500	1000	2000	4000	8000	
Jumbo (Three Drills)	89	100	109	109	109	107	108.5	109.5	106	115.24
Drill Hydrofore	68	79	86	99	96	99	99	99	94	105.2
Jaw Crusher	89	94	94.5	94.5	94.5	94.5	94	97	88	101.64

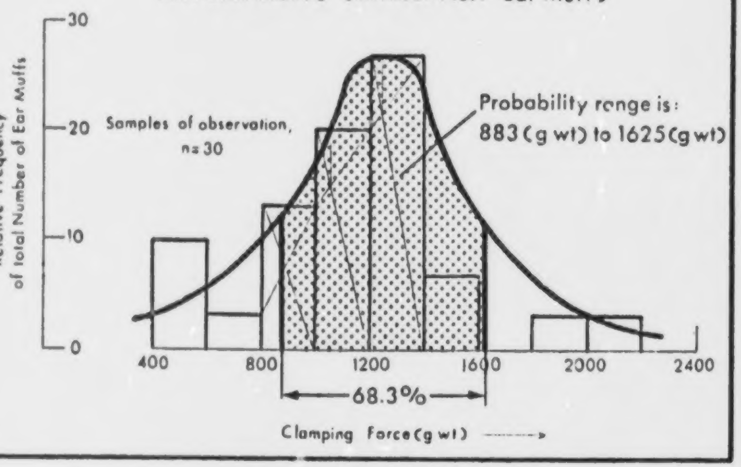
Total noise estimated from the octave-band noise levels given in the first nine columns.

TABLE 7

Summary of Clamping Force Survey Data

Type of Equipment	 D (cm)	Clamping Force (gwt		Mean	Std. Dev.	Number of Items					
						Clamping Force (g wt)					Σ
		Lower	Upper			400-800	800-1200	1200-1600	1600-2000	>2000	
Jumbo (3 Drills) Operator	12.8	430	1960	1168	443	2	4	3	2	-	11
Drill Hydrofore Operator	13.8	580	2110	1327	456	1	3	5	-	2	11
Jaw Crusher Operator	13.5	580	2060	1273	447	1	6	3	-	1	11
Average	13.4	430	2110	1256	440	4	13	11	2	3	33


ELEVEN EAR MUFFS


TEN EAR MUFFS (without No. 7 Ear Muff)

$$Z = \frac{(\overline{X}_1 - \overline{X}_2)}{\sigma_d} \qquad \text{(Eq. 2)}$$

where: Z = a standardized variable and is a dimensionless quantity (i.e., is independent of units used),

and, $$\sigma_d^2 = \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2} \qquad \text{(Eq. 3)}$$

This is a one-sided test, since we are checking the null hypothesis $\overline{X}_1 = \overline{X}_2$ $\overline{X}_1 > \overline{X}_2$. We find the probability of obtaining by chance a value of Z of at least this magnitude as (0.5000 - 0.0279) = 0.4721 = 47.21 percent. We conclude that the observed difference in means of the clamping forces considering eleven muffs or ten muffs could occur by random variation in 94.42 percent of the observations. Therefore, the difference is not significant, but due to chance error within 5.58 percent, which is trivial. The clamping forces vary from 430 (g wt) to 2110 (g wt). The mean value is 1256 ± 77 (g wt) (Standard error is ± 77 (g wt) (Table 7). In various references in the literature it can be found that a clamping force can vary between 500 and 1000 grams (13). Many manufacturers' catalogues contain no information about clamping forces. Only the Mark IV, MSA, model's specifications claim that the head pressure (clamping force) is, at 14.2 cm: 1191 (g wt) (14). According to the calculated mean, this would correspond to 1256 - 77 = 1179 (g wt) at 13.4 cm. The data in the literature differs from practical data. Manufacturers have increased clamping forces in their products thus creating discomfort for the wearer. They did this because they are well aware that too small a pressure results in the creation of air leaks.

3.7. Discussion

Assuming that ear muffs are excellent attenuators (which they are not), and that a miner is working under noise levels of 115 dBA (Jumbo-Three Drills), then he would have to wear his muffs 95 percent of the drilling time to lower his exposure to within the 85 or 90 dBA limit. Taking his muffs off for 12 minutes in a four hour drilling period would over-expose the miner to noise. Most hearing loss occurs in the first five years of exposure to noise (15). A man who has worked in noisy environments for 25 years gains no practical benefit from even the most powerful muffs (16). Of course, safety organizations in mines must be capable of performing the task of controlling attenuation of ear muffs.

Two types of safety organizations exist in Canadian mines. The first is in effect in smaller mines and safety is the specific responsibility of all management. Staff safety organizations are used at medium and large mines. The safety program is headed by supervisory personnel. They are not responsible for production and should not give orders to miners. It is considered that the foreman is the key to the entire accident prevention problem. He is in the best position to put safety into practice, and must become capable in doing so through experience and training. Miners must be induced to cooperate in the training.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

Exposure to noise of sufficient intensity for long periods of time can produce detrimental changes in the inner ear and decrease the ability to hear. Noise pollution has been recognized as a hazardous problem in Canadian mines and mills. Mechanization in mines has resulted in higher noise levels. Persons operating machines that produce excessive noise, and miners in close proximity, are exposed to high noise levels. These miners are required unconsciously to make use of their decision-making abilities in determining the effects of noise on peripheral vision, the amount of muscle tension required to do the task, spatial positioning of the head, the processing of communicative information, and other aspects of performance. An analysis showed that Canada has made great efforts in the abatement of noise in mines. The high cost of fully implementing a 90 dBA noise standard, and to comply with the 85 dBA noise standard, requires that we develop very inexpensive and very effective methods in the battle against noise in mines.

The most important function of an ear muff is that it will attenuate noise whilst providing a comfortable fit. Manufacturers claim that ear muffs are shaped to fit all ears comfortably; this is not always the case. Some of the main problems encountered in ear muffs are caused by the ear cushion seal against the head and their functional design.

The noise levels reaching the ears were calculated by a computer model for ear muffs fitted by either the octave-band or the sound level conversion method. The method provides an acceptable basis for selecting ear muffs in any industrial noise spectrum not dominated by intense pure tone or narrow-band energy components.

Methods using short measurements for the determination of a noise exposure index, and modes of control for good muff wearing, were developed in the Elliot Lake Laboratory. Tests in mines showed that only three ear muffs of all examined have good attenuations (Table 6):

- No. 5, model E: (23.3 dBA)
- No. 6, model F: (19 dBA), and
- No. 10, model J: (22.1 dBA).

All three ear muffs are worn behind the head. The No. 10 muff has a support strap which improves comfort and maintains a good fit during wear. Causes of poor attenuation are numerous: bad mounting of ear muffs on helmets, improper fitting, interference by hair and eyeglasses, improper wearing by miners, unsatisfactory enforcement by supervisory personnel, incomplete training of miners, etc.

Results of this research have indicated that none of the currently manufactured ear muffs tested in this study contain all of the characteristics desirable in an ideal unit.

Today, in Canadian mines, ear muffs are a part of safety equipment such as helmets, masks, safety glasses, gloves and safety boots. Because of this a new effort has been made to obtain a detailed analysis of ear muffs to improve their application under working conditions.

4.2. Recommendations

1. The results suggest that obligatory tests, which were developed in the Elliot Lake Laboratory for ear muff attenuation, should be introduced. These tests require only two dosimeters and a stop watch, or only two profiling dosimeters (a pocket-sized computer). Portable instruments

that monitor the real attenuation of ear protectors while worn at the work station, exist on the market. These instruments are impractical in mines because they slow down the normal work pace, thus changing the noise level.

2. because of unsatisfactory ear muff attenuation in working conditions, it should be a mandatory requirement that workers wear ear muffs and ear plugs if the noise level is higher than 105 dBA (various references in the literature recommend 110 dBA).
3. It is recommended that miners use support straps to maintain effective attenuation and positioning of ear muffs which are worn behind the head. To convince the employee of the importance of a hearing conservation program requires planning, educational effort, persistent control and assistance.
4. Foremen must be capable, through experience and training, to help and control miners in their task of properly wearing ear muffs.
5. Introduce the program to new miners at the start of employment.
6. When purchasing ear muffs, practical attenuation results should be taken into account, because the greatest noise reduction is not always given by ear muffs which have the best attenuation characteristics in the laboratory.
7. Constant contact must be maintained with manufacturers to improve designs, maintenance, and servicing of ear muffs.

5. ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Mines Accident Prevention Association of Ontario for providing a selection of ear muffs for this project. He is also indebted to E. D. Dainty, Project Leader, CEAL; Dr. R. Tervo, Manager, G. Knight, Research Scientist, and Dr. N.K. Davé, Research Fellow, Elliot Lake Laboratory, who were helpful in many ways. Grateful acknowledgement is given to A. Webster who transcribed and completed the tables from the raw data. He acknowledges the contribution of H. Poliquin for his assistance in field work.

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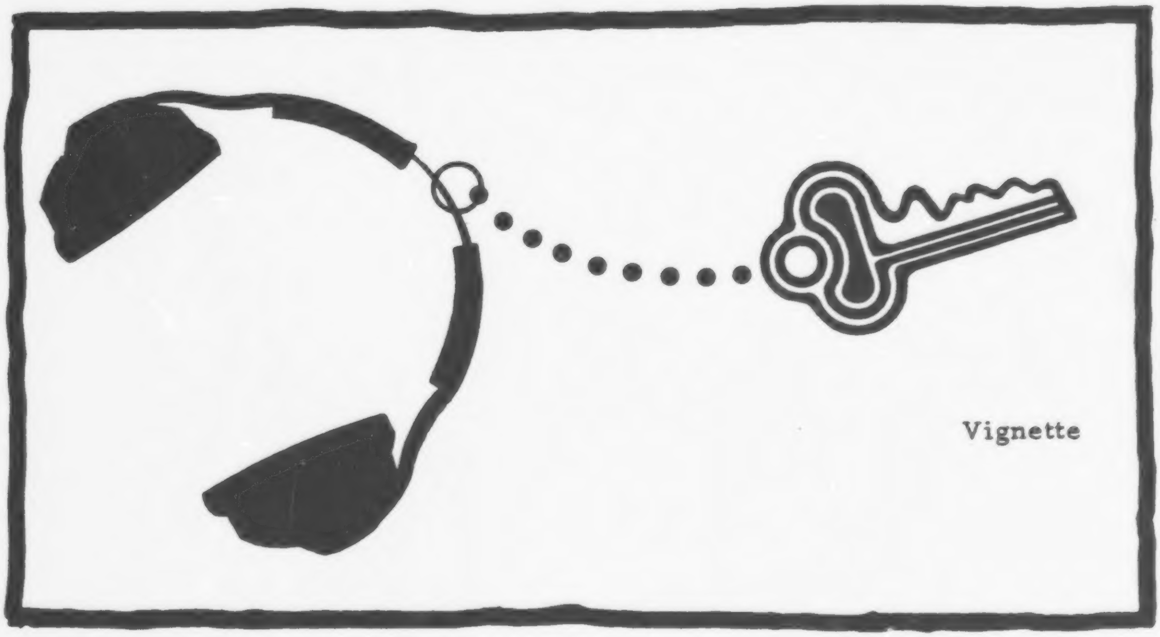
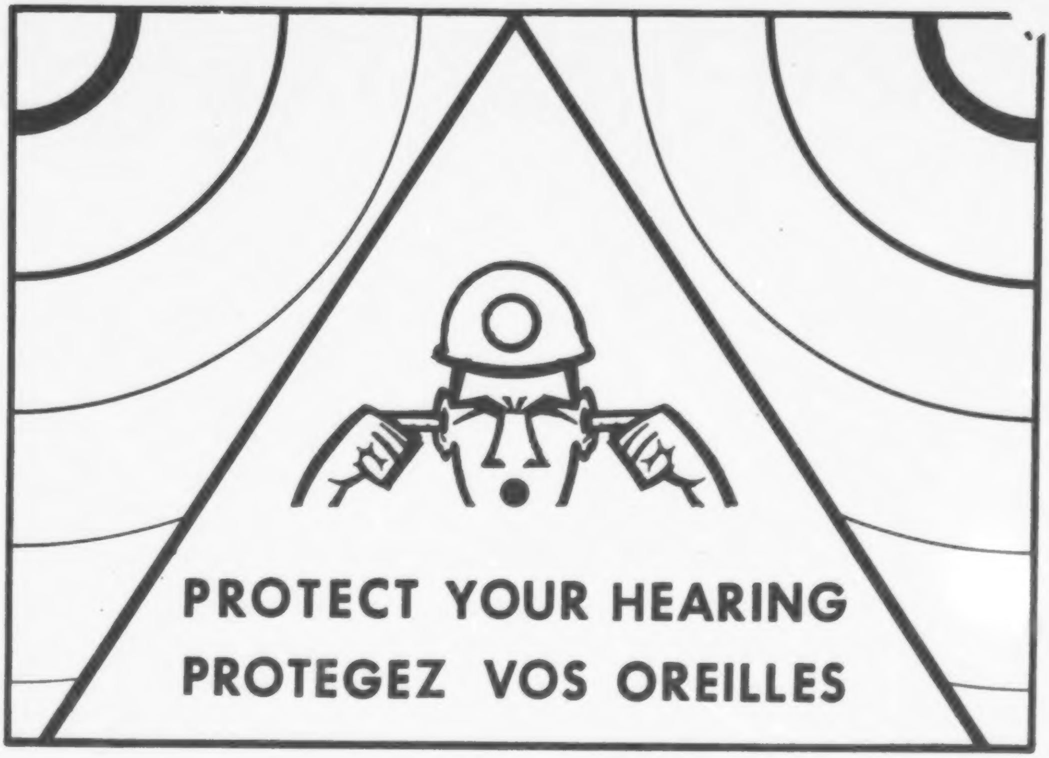



PROTECT YOUR HEARING
PROTEGEZ VOS OREILLES

Vignette

APPENDIX A

Programs

Program
Computation of Equivalent Continuous Sound Level (L_{eq})
Using a Hewlett-Packard HP-35

L_{eq} is defined mathematically by (Appendix F) (17):

$$L_{eq} = \frac{q}{\log_{10} 2} \log_{10} \left[\frac{1}{T} \int_0^T \left(\frac{p(t)}{p_o} \right)^{\frac{20 \log_{10} 2}{q}} dt \right] \qquad \text{(Eq. 7)}$$

The OSHA has $q = 5$, and

$$L_{eq} = 16.6 \log_{10} \left[\frac{1}{T} \int_0^T \left(\frac{p(t)}{p_o} \right)^{1.2} dt \right]$$

where: $$dB = 10 \log \left(\frac{p}{p_o} \right)^2 \qquad \text{(Eq. 8)}$$

or: $$\frac{p}{p_o} = \sqrt{\text{antilog} \frac{dB}{10}}$$

Evaluation:

Step No.	Enter Data	Operation	
		Enter	Press
1	L_{p1}	-	ENTER↑
2	-	10	÷
3	-	10	x^y, √
4	t_1	-	×
4a	-	-	-
5	L_{p2}	-	ENTER↑
6	-	10	÷
7	-	10	x^y, √
8	t_2	-	×, +
8a	-	-	-
Repeat lines 5, 6, 7 and 8 for all values of L_p from L_{p3}, L_{p4}, etc. and t_3, t_4, etc.			
9	-	-	LOG
10	-	1.2	×
11	-	10	x^y
12	t_1	-	ENTER↑
13	t_2	-	+
Repeat line 13 for all values of t_3, t_4, etc.			
14	-	-	÷ LOG
14a	-	-	-
15	-	16.6	×

These computations assume that the sound level is constant for the time interval considered.

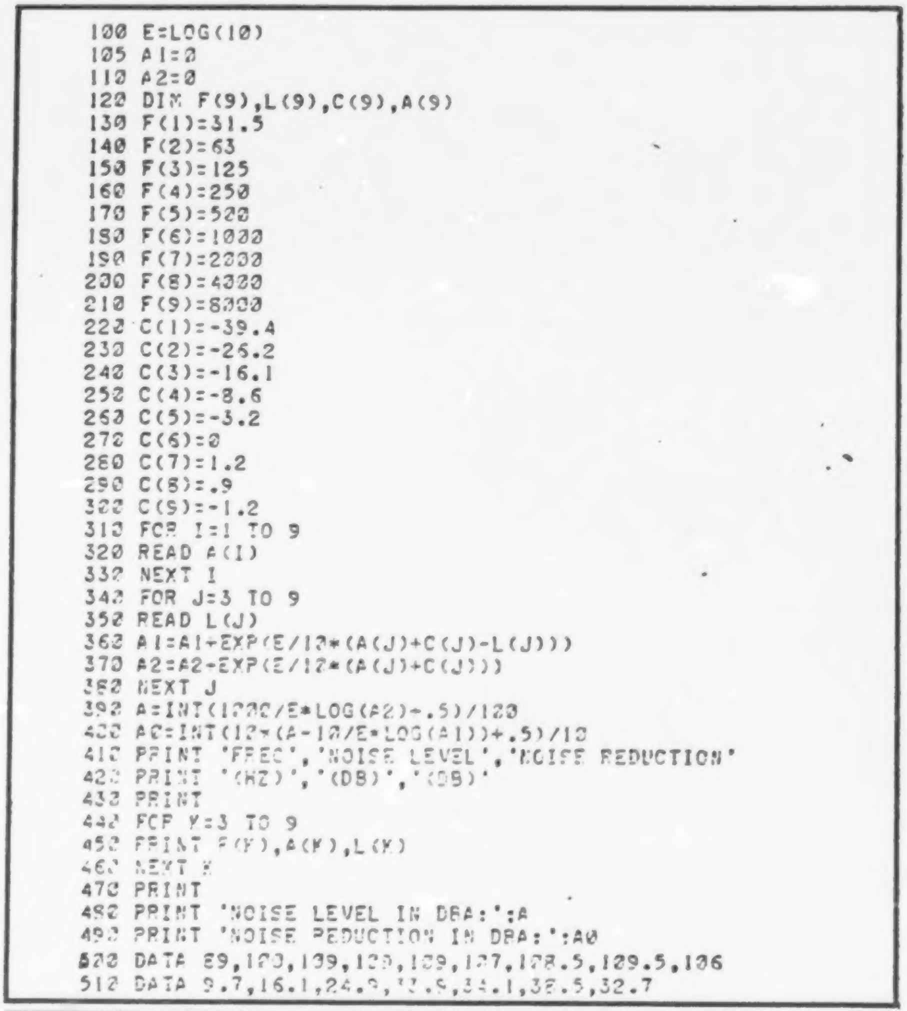
Program
Calculate A-Weighted Sound Level from Octave Band Levels Using a Hewlett-Packard HP-35

Step No.	Enter Data	Operation		Step No.	Enter Data	Operation	
		Enter	Press			Enter	Press
1	$L_{31.5}$	-	ENTER ↑	20	-	10	x^y
2	-	39.4	—	21	L_{1k}	-	ENTER ↑
3	-	10	÷	22	-	10	÷
4	-	10	x^y	23	-	10	x^y
5	L_{63}	-	ENTER ↑	24	L_{2k}	-	ENTER ↑
6	-	26.2	—	25	-	1.2	+
7	-	10	÷	26	-	10	÷
8	-	10	x^y	27	-	10	x^y
9	L_{125}	-	ENTER ↑	28	L_{4k}	-	ENTER ↑
10	-	16.1	—	29	-	0.9	+
11	-	10	÷	30	-	10	÷
12	-	10	x^y	31	-	10	x^y
13	L_{250}	-	ENTER ↑	32	L_{8k}	-	ENTER ↑
14	-	8.6	—	33	-	1.2	—
15	-	10	÷	34	-	10	÷
16	-	10	x^y	35	-	10	x^y, +
17	L_{500}	-	ENTER ↑	36	-	-	LOG
18	-	3.2	—	37	-	10	×
19	-	10	÷				

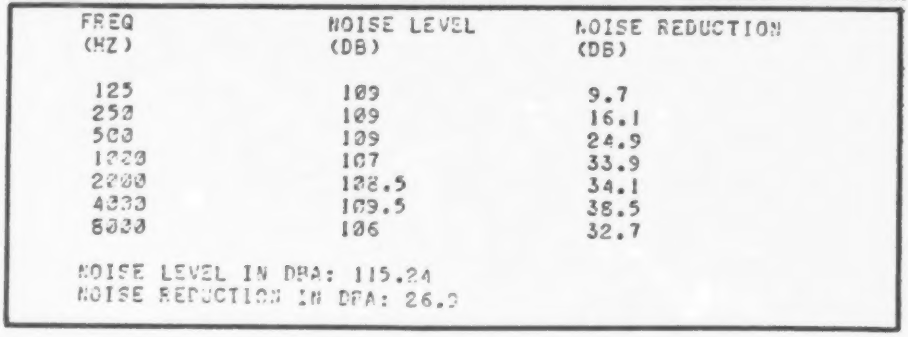
Note:

Step No. 1, for data beginning at 31.5 Hz octave band.
Step No. 5, for data beginning at 63 Hz octave band.
Step No. 9, for data beginning at 125 Hz octave band.

Computer Program for Calculating the Effective Noise Reduction (Attenuation) of Ear Muffs



```
100 E=LOG(10)
105 A1=0
110 A2=0
120 DIM F(9),L(9),C(9),A(9)
130 F(1)=31.5
140 F(2)=63
150 F(3)=125
160 F(4)=250
170 F(5)=500
180 F(6)=1000
190 F(7)=2000
200 F(8)=4000
210 F(9)=8000
220 C(1)=-39.4
230 C(2)=-26.2
240 C(3)=-16.1
250 C(4)=-8.6
260 C(5)=-3.2
270 C(6)=0
280 C(7)=1.2
290 C(8)=.9
300 C(9)=-1.2
310 FOR I=1 TO 9
320 READ A(I)
330 NEXT I
340 FOR J=3 TO 9
350 READ L(J)
360 A1=A1+EXP(E/10*(A(J)+C(J)-L(J)))
370 A2=A2+EXP(E/10*(A(J)+C(J)))
380 NEXT J
390 A=INT(1000/E*LOG(A2)+.5)/100
400 A0=INT(10*(A-10/E*LOG(A1))+.5)/10
410 PRINT 'FREQ','NOISE LEVEL','NOISE REDUCTION'
420 PRINT '(HZ)','(DB)','(DB)'
430 PRINT
440 FOR K=3 TO 9
450 PRINT F(K),A(K),L(K)
460 NEXT K
470 PRINT
480 PRINT 'NOISE LEVEL IN DBA:';A
490 PRINT 'NOISE REDUCTION IN DBA:';A0
500 DATA 89,100,109,109,109,107,108.5,109.5,106
510 DATA 9.7,16.1,24.9,33.9,34.1,38.5,32.7
```



```
FREQ                NOISE LEVEL          NOISE REDUCTION
(HZ)                (DB)                 (DB)

 125                 109                  9.7
 250                 109                  16.1
 500                 109                  24.9
 1000                107                  33.9
 2000                108.5                34.1
 4000                109.5                38.5
 8000                106                  32.7

NOISE LEVEL IN DBA: 115.24
NOISE REDUCTION IN DBA: 26.3
```

APPENDIX B

Ear Muff Noise Attenuation Survey Forms

ELLIOT LAKE LABORATORY, CANMET, E.M.R.

SHEET: 4

Ear Muff Noise Attenuation Survey Form

EQUIPMENT TESTED (SEE OTHER SIDE FOR DETAILS): JUMBO, Seco Drills-3

EAR MUFF: MSA Mark IV

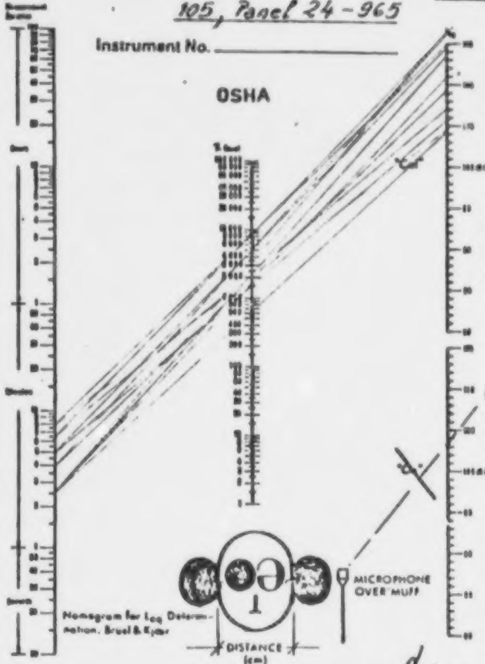
Date: May 19, 1977

Location: Local Mines Ltd. 105, Panel 24-965

Instrument No.

COMFORT: 1 2 3

PRICE/UNIT ($): 5 6 7 8 9 10 11 12



RIGHT SIDE

%Count	Time(min)	L_{eq}(dBA)
3480	2:30	117.0
5000	4:00	116.4
8580	6:30	116.4
	3/3	116.6

%Count	Time(min)	L_{eq}(dBA)
1570	2:30	111.0
1970	4:00	109.2
2450	6:30	107.0
	3/3	109.2

LEFT SIDE

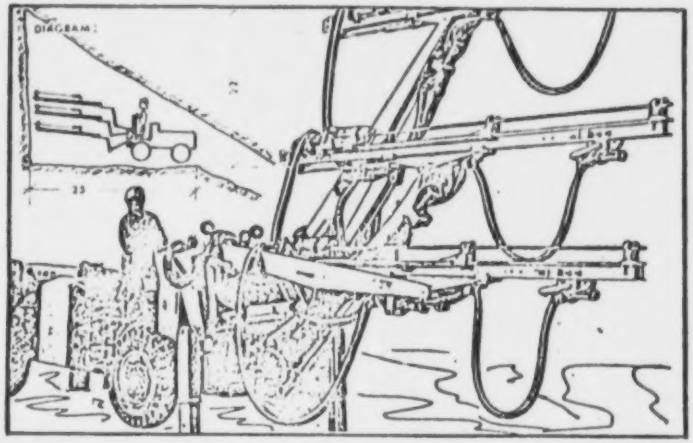
%Count	Time(min)	L_{eq}(dBA)
2300	2:30	113.8
5250	5:00	114.3
8600	8:00	115.0
	3/3	114.4

%Count	Time(min)	L_{eq}(dBA)
630	2:30	104.3
1500	5:00	105.7
2060	8:00	104.3
	3/3	104.8

SIGNED Savich

DISTANCE 13 14 15 16 17 18 19 20 21 22(cm)

ELLIOT LAKE LABORATORY, CANMET, E.M.R.



SUBJECT: SECO (S.AFRICA) - JUMBO, Seco Drills-3

Model:
Manufacturer: SECO
Serial:
Rated Speed and Capacity:
Description: Three drill jumbos can be used in driving drifts or tunnels with great variations in cross section.

TECHNICAL DATA:

Steel type:	Water Pressure Supplied: bars
Length: metres	Airflow: m^3/min
Bit Type:	Blow Rate: blow/min
Muffler Type:	Penetration: m/min
Air Pressure Supplied: bars	Rock Type: Uraniferous Conglomerate

NOTES: Jumbo operator should wear ear muffs and ear plugs.

ELLIOT LAKE LABORATORY,CANMET,E.M.R.

SHEET: 3

Ear Muff Noise Attenuation Survey Form

EQUIPMENT TESTED(SEE OTHER SIDE FOR DETAILS): WAGON DRILL HYDROFORE - MONTABERT -

EAR MUFF: NO NOISE Hellberg Protection AB, Sweden

Date: May 16, 1977

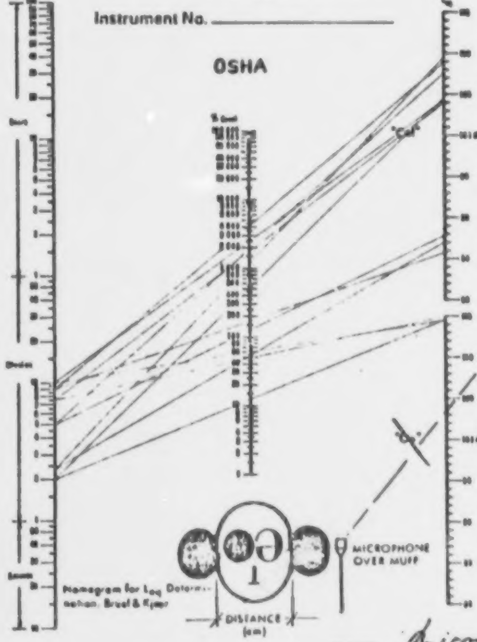
COMFORT

Location: Local Mines Ltd. - Panel 24

PRICE/UNIT

Instrument No.

OSHA



RIGHT SIDE

% Count	Time (min)	Leq (dBA)
1250	2:15	109.5
2070	5:00	107.7
4470	9:00	108.8
	⅔	108.7

% Count	Time (min)	Leq (dBA)
58	2:15	87
130	5:00	88
170	9:00	86
	⅔	87

LEFT SIDE

% Count	Time (min)	Leq (dBA)
530	2:00	104.5
1690	7:30	104
2510	10:30	104.2
	⅔	104.2

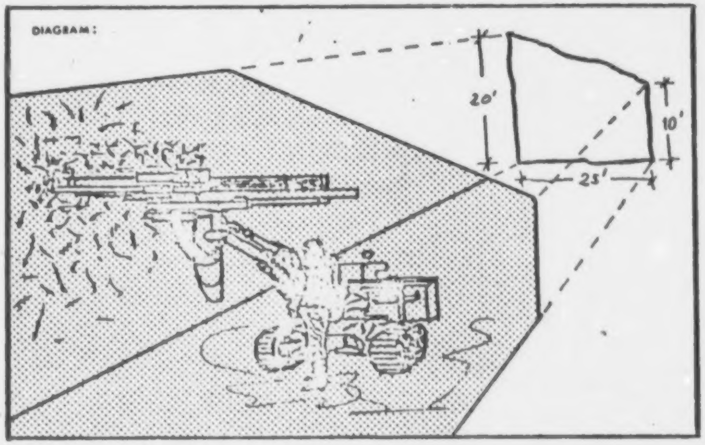
% Count	Time (min)	Leq (dBA)
13	2:00	~77
50	7:30	~77
62	10:30	~77
	⅔	77

DISTANCE

SIGNED Lirony Savich

ELLIOT LAKE LABORATORY, CANMET, E.M.R.

DIAGRAM:



SUBJECT: TRACK MOUNTED WAGON DRILL HYDROFORE

Model: H 100 Manufacturer: Montabert Serial:

Rated Speed and Capacity:

Description: Montabert offers an option of the H100: the H100FR drifter. During extraction of rods, the piston strikes at full power on shank, without transmission of shocks to component parts of drifter. Rod extraction, without damaging the equipment is thus made far easier.

TECHNICAL DATA:

Steel type: hex. 38 (1½")

Length: 1.83 (6Ft) metres

Bit Type: Cross, ϕ51mm (2")

Muffler Type:

Air Pressure Supplied: 100 bars

Waterflushing requirements: 20l/min (4½ ...)

Airflow: 4.5 (150) m³/min

Blow Rate: 1400 blow/min

Penetration: ~0.7 (38 Ins/min) m/min

Rock Type: Uraniferous Conglomerate

NOTES: Drill operator should wear ear muffs and ear plugs.

ELLIOT LAKE LABORATORY, CANMET, E.M.R.

SHEET: 9

Ear Muff Noise Attenuation Survey Form

EQUIPMENT TESTED (SEE OTHER SIDE FOR DETAILS): JAW CRUSHER

EAR MUFF: David Clark Co. Inc.
Model E-705

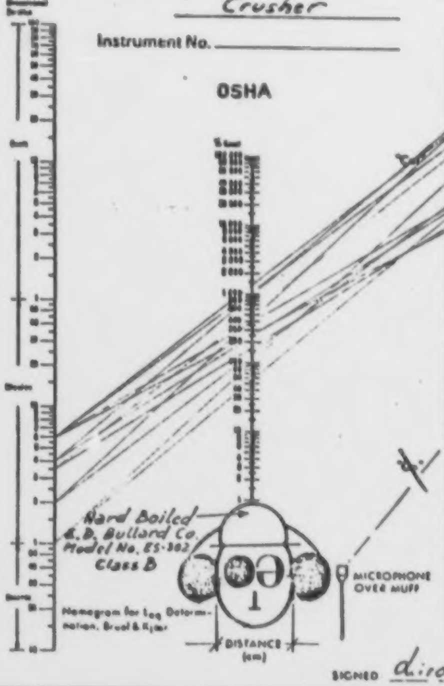
Date: May 13, 1977

Location: Local Mines Ltd.
Crusher

Instrument No. ______

COMFORT: [✓ 1] 2 3

PRICE/UNIT ($): 3 4 7 8 9 10 11 12


OSHA
Hard Boiled
E.D. Bullard Co.
Model No. ES-302
Class B
MICROPHONE OVER MUFF
Nomogram for Leq Determination, Bruel & Kjaer
DISTANCE (cm)

RIGHT SIDE

% Count	Time (min)	Leq (dBA)
420	2:08	103.2
950	4:00	104.3
1360	6:00	103.5
	3/3	103.7

% Count	Time (min)	Leq (dBA)
140	2:00	~95
240	4:00	94.2
370	6:00	94.8
	3/3	94.7

LEFT SIDE

% Count	Time (min)	Leq (dBA)
100	1:00	98.1
540	3:30	100.9
1015	6:00	102.1
	3/3	100.3

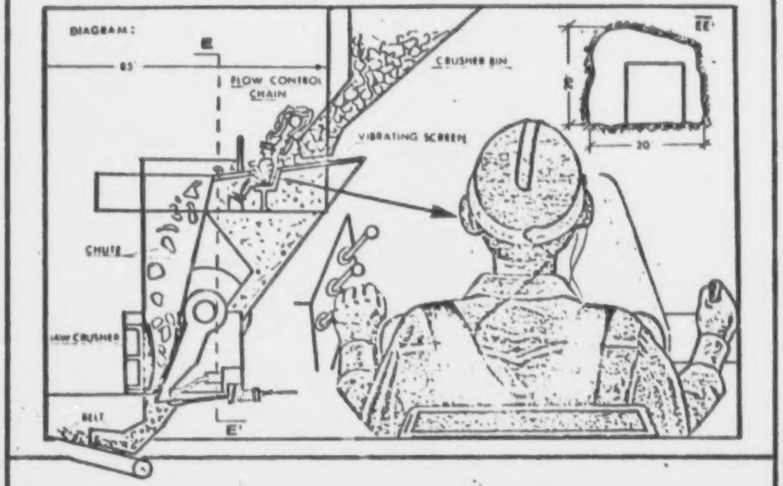
% Count	Time (min)	Leq (dBA)
57	1:00	94.5
160	3:30	92.3
262	6:00	92
	3/3	92.9

DISTANCE 13 14 15 16 17 18 19 20 21 22 (cm)

SIGNED diroy Sarich

ELLIOT LAKE LABORATORY, CANMET, E.M.R.

DIAGRAM:


85'
E
FLOW CONTROL CHAIN
CRUSHER BIN
VIBRATING SCREEN
CHUTE
JAW CRUSHER
BELT
E'
EE'
R
20'

SUBJECT: JAW CRUSHER

Model: ______ Manufacturer: ______ Serial: ______

Rated Speed and Capacity: ~ 600 t/h to 700 t/h

Description: ______

TECHNICAL DATA:

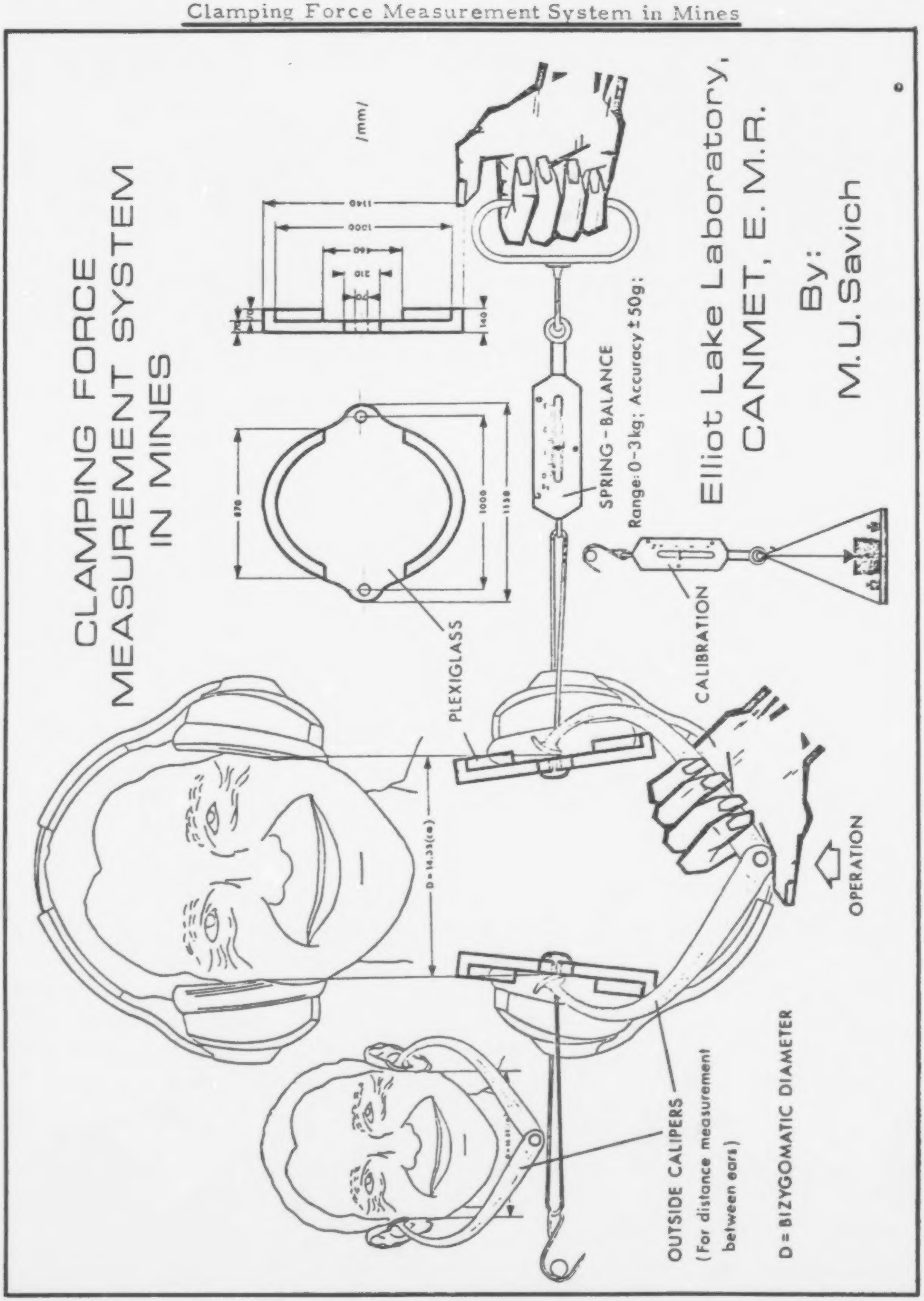
Steel type: ______	Water Pressure Supplied: ______ bars
Length: ______ metres	Airflow: ______ m³/min
Bit Type: ______	Blow Rate: ______ blow/min
Muffler Type: ______	Penetration: ______ m/min
Air Pressure Supplied: ______ bars	Rock Type: Uraniferous Conglomerate

NOTES: Measurements taken at crusher operator control panel.
Crusher operator should wear ear muffs, or ear plugs.

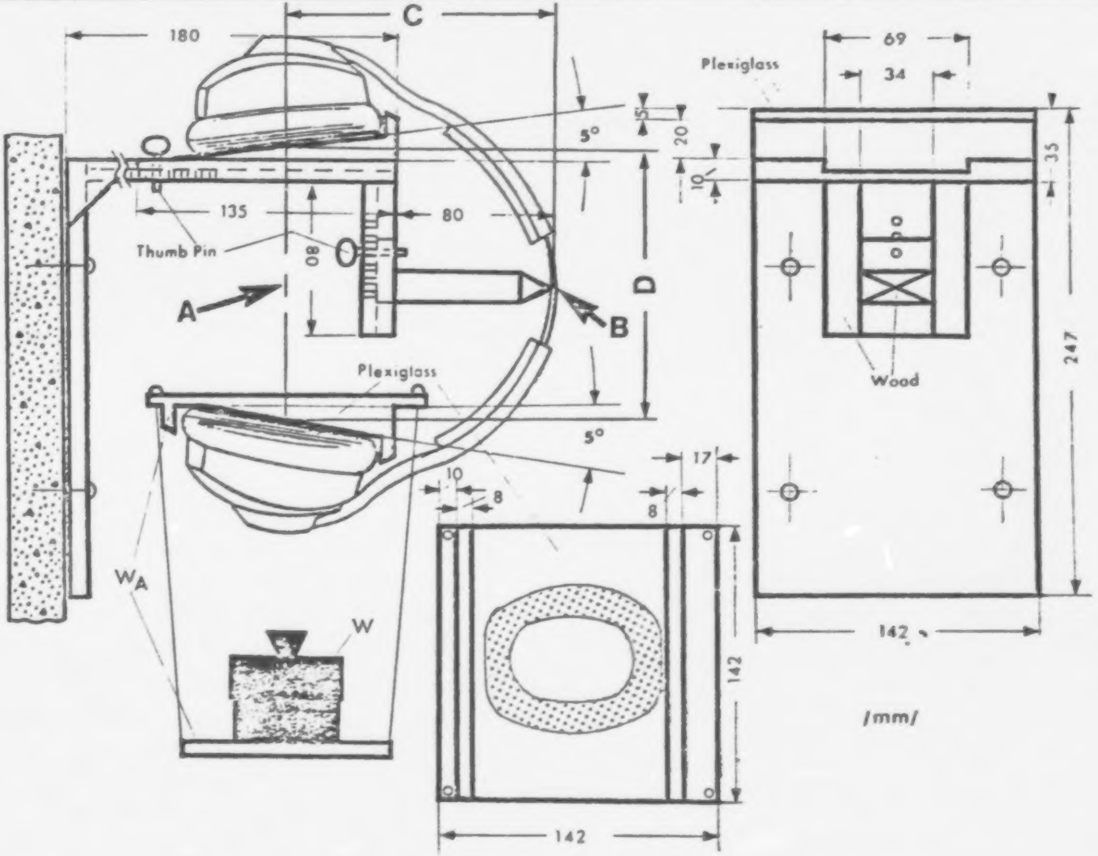
APPENDIX C

Force Measurement Systems

Clamping Force Measurement System in Mines


CLAMPING FORCE
MEASUREMENT SYSTEM
IN MINES
/mm/
1140
1000
460
210
70
140
870
1000
1130
PLEXIGLASS
SPRING-BALANCE
Range: 0-3kg; Accuracy ± 50g;
CALIBRATION
Elliot Lake Laboratory,
CANMET, E.M.R.
By:
M.U. Savich
D=14.35(cm)
OPERATION
OUTSIDE CALIPERS
(For distance measurement
between ears)
D = BIZYGOMATIC DIAMETER

Headband Force Apparatus (Elliot Lake Laboratory)


C
180
Plexiglass
69
34
5°
5
20
10
35
135
80
Thumb Pin
80
A
B
D
Wood
247
Plexiglass
5°
17
10
8
8
W_A
W
142
142
/mm/
142

Clamping force measurement of ear muffs with headband.

NOTES:

1) A: Centreline passes through pivot point of earcup attachment to headband.
   B: After correct head band distance is obtained (operator's head size), move out of the way for force measurement.
   C: Correct operator's head size.
   D: Bizygomatic Diameter (D).

2) Construction: Almost any material can be used: wood, steal, plexiglass, etc.

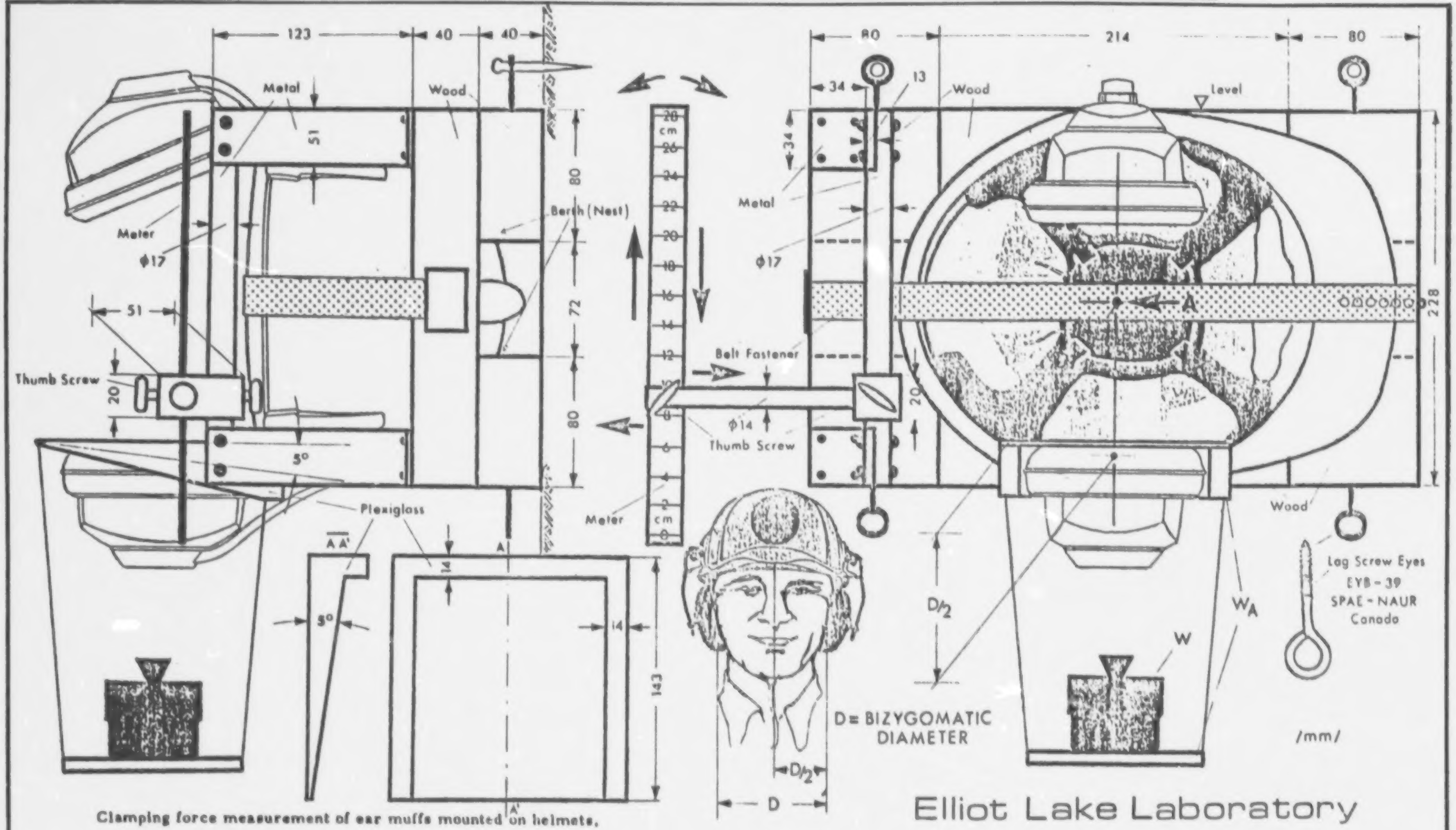
3) Calibration: No calibration. When measuring, the attachment weight must be taken into account. Clamping force (g wt) = W_A + W (where W_A is the attachment weight, and W is the weight).

4) Operation: As shown in Fig. above.

5) Accuracy: ± 10 g.

Elliot Lake Laboratory
CANMET, E.M.R.
By: M.U.Savich

Apparatus for Clamping Force Measurements on Helmet (Elliot Lake Laboratory)


123
40
40
Metal
Wood
51
Meter
ϕ17
51
Thumb Screw
20
5°
Plexiglass
80
72
80
Berth (Nest)
A
A'
$\overline{AA'}$
5°
14
14
143
cm
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Meter
Belt Fastener
ϕ14
Thumb Screw
80
214
80
34
34
13
Wood
Level
Metal
ϕ17
A
228
20
Wood
D/2
W_A
W
Lag Screw Eyes
EYB - 39
SPAE - NAUR
Canada
D = BIZYGOMATIC DIAMETER
D/2
D
/mm/

Clamping force measurement of ear muffs mounted on helmets.

Elliot Lake Laboratory

CANMET, E.M.R. ©

NOTE:

1) A: Centreline passes through pivot point of ear cup attachment to hat (helmet).
2) Construction: Almost any material can be used: wood, steel, plexiglass etc.
3) Calibration: With lag screw eyes both edges of the apparatus are placed horizontally using a level. No calibration with weight.
4) Arrangement: The hat is placed on a berth (nest) lined with rubber and the belt fastener is well tightened.
5) Operation: Measurement should be done for one earcup first. The apparatus is then turned 180°, and measurement is done for the other cup. By this method, assymetry of clamping force can be measured. When measuring, the attachment weight must be taken into account. Clamping force (g wt) = $W_A + W$ (where: W_A is the attachment weight, and W is the weight).
6) Accuracy: ± 10 g.

By: M.U.Savich

APPENDIX D

Glossary

GLOSSARY

For convenience, definitions of terms which are used in the report are assembled here. Many definitions were taken from documents prepared by ISO, ANSI and listed references.

A

A-weighting Network: See Weighting Network.

Absorbents, Sound: Materials that absorb sound readily. These are usually construction materials designed specifically for the purpose of absorbing acoustic energy.

Absorption Loss: That part of the transmission loss due to the dissipation or conversion of sound energy into other forms of energy (for example, heat), either within the medium or attendant upon a reflection.

Accuracy: The relationship of the measured value to the actual value.

Acoustics: The science of sound, including its production, transmission and effects.

Adapters: Effective barrier for people wearing glasses in conjunction with hearing protectors. They can be worn with any muff-type hearing protector.

Ambient Noise: See Background Noise.

ANSI: The American National Standards Institute.

Attenuation, Sound: The reduction, expressed in decibels, of the sound intensity.

Audio Frequency: An audio frequency is any frequency corresponding to a normally audible sound wave.

Audiometry: The science of measurement of hearing ability.

B

B-Weighting Network: See Weighting Network.

Background Noise: Background noise is the total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal.

Band-Centre Frequency: The designated (geometric) mean frequency of a band of noise or other signal. For example, 1000 Hz is the band centre frequency for the third-octave band that extends from 891 to 1123 Hz.

Bar: See Microbar.

Bel: A unit of sound level when the base of the logarithm is 10. See also Decibel.

Bizygomatic Diameter (D): Maximum distance between the bony structures (zygomatic arches) forward of the ears.

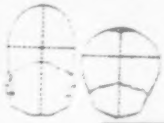
Brachycephalic Head: See Cephalic Index.

Broadband: A wide frequency range. Sound whose energy is distributed over a broad range of frequency (generally, more than one octave).

C

C-Weighting network: See Weighting Network.

Cephalic Index:



Dotted lines in the brachycephalic (right) and dolichocephalic (left) skulls indicate measurements taken.

No.	Head	Cephalic Index
1	Dolichocephalic	< 75
2	Mezzocephalic	75 - 80
3	Brachycephalic	> 80

Census: Official numbering of population with various statistics.

Clamping Force, (Head force): The force exerted by ear muffs on the skin.

Cochlea: The auditory part of the internal ear, shaped like a snail shell, containing the basilar membrane on which are distributed the end organs of the acoustic or eighth cranial nerve.

Communication: The signals or stimuli (or their transmission) which produce reactions, orient us in our environment and furnish information on which to base decisions.

Compliance:

a) Compliance is the reciprocal of stiffness.
b) To conform or adapt to applicable laws and standards.

Cycle: A cycle is the complete sequence of values of a periodic quantity that occur during a period.

Cycle per second (Hz): A unit of frequency in hertz.

D

Damage-Risk Criterion: Damage-risk criterion specifies the maximum allowable exposure to which people impairment is to be avoided. A damage-risk criterion may include in its statement a specification of such factors as time of exposure, noise intensity, and frequency, amount of hearing loss that is considered significant, percentage of the population to be protected, and method of measuring the noise.

Damping: Damping is the dissipation of energy with time or distance.

Data Analysis: The analysis of environmental data, usually in reduced form, for some intended purpose, such as prescription of design criteria or test environments or estimation of the degree of environmental hazard in a new situation.

Data Measurement: A measurement of the environment, not necessarily as part of an orderly or extensive plan, that provides either raw data or results of simple data reduction.

Data Reduction: The processing of data so as to present it in more useful form and focus on the more important aspects for an intended purpose.

Deaf: Unable to hear, hard of hearing.

Deafness: Loss of ability to hear without designation of degree of loss or cause.

Decibel (dB): A non-dimensional unit used to express sound levels. The decibel is a unit of level which denotes the magnitude of a quantity with respect to an arbitrarily established reference value of the quantity, in terms of the logarithm (to the base 10) of the ratio of the quantities:

$$dB = 10 \log_{10} \left(\frac{p}{p_o} \right)^2 \qquad \text{(See Appendix A-1)}$$

where: p is the effective, root mean square sound pressure, and p_o is the reference pressure for airborne sound $2 \times 10^{-5} N/m^2$ or 20μ Pa. Decibel values will be used and tabulated according to their measurement procedures or spectrum characteristics.

NOTE:

The average $\overline{SPL}$ (sound pressure level) is calculated by the following equation:

$$\overline{SPL} = 10 \log \frac{1}{n} \left[\text{antilog} \frac{SPL_1}{10} + \text{antilog} \frac{SPL_2}{10} + \dots \text{antilog} \frac{SPL_n}{10} \right]$$

The calculation can be simplified if the maximum variation in levels is small. When the variation is 5 dB or less, the average of the levels can be found by averaging them arithmetically. If the maximum variation is between 5 and 10 dB, the average can be calculated by taking the arithmetic average and adding 1 dB.

Decibel Characteristics

Decibel Specification	Characteristics
dBA*	A-Weighting scale used.
dB (Pure)	Pure tone pressure level.
dB (Octave)	Octave band widths used.
dB (Overall)	Overall pressure level, no weighting used.
dB (Spectrum)	Spectrum level based on one hertz bandwidth.

* A sound level reading in decibels made on the A-weighted network of a sound level meter.

Dolichocephalic Head: (See Cephalic Index).

Dosimeter: A device worn on the person for determining the accumulated sound exposure with regard to level and time.

Dynamic Range: That region of measurement of an instrument or system between the noise floor and maximum permissible distortion point.

E

Ear Protector: A device worn to reduce the passage of ambient noise into the auditory system. Ear plugs are inserted in the external ear canal. Ear muffs fit over the entire ear and snug against the head.

Efficiency: The efficiency of a device with respect to a physical quantity is the ratio of the useful output of the quantity to its total input.

Environment: The surrounding conditions generated as a result of the operation of a structure or equipment.

EPA: The Environmental Protection Agency, U.S.A.

Equivalent Continuous Sound Level (L_{eq}): L_{eq} is defined mathematically by:

$$L_{eq} = \frac{q}{\log_{10} 2} \log_{10} \left[\frac{1}{T} \int_{0}^{T} \left(\frac{p(t)}{p_o} \right)^{\frac{20 \log_{10} 2}{q}} dt \right] \text{(See Appendix A-1)}$$

where: q is 5(5 dBA increase for halving of duration, OSHA).
T is the total sampling period in hours,
p(t) is the instantaneous A-weighted sound pressure in Pa (pascal),
t is the time in hours.
When the sound level is constant, L_{eq} is equal to the reading of a sound level meter. When the sound level is not constant, direct indication of L_{eq} requires an expensive, highly specialized instrument.

F

Frequency: The frequency of a function periodic in time is the reciprocal of the period. The unit is the cycle per unit time and must be specified; the unit cycle per second is called hertz (Hz).

G

Gaussian Normal Distribution: A distribution in which the mean coincide at the apex of a symmetrical bell-shaped curve of frequency of occurrence plotted against magnitude of the measurement.

g wt, (g wt): gram weight.

H

Hearing: The subjective response to sound and the nervous and cerebral operations which translate the physical stimuli into meaningful signals.

Hearing Conservation: The prevention or minimizing of noise induced hearing loss through the use of hearing protection devices and the control of noise through engineering methods or administrative procedures.

Hearing Loss: An increase in the threshold of audibility, at specific frequencies, as the result of normal aging, disease, or injury to the hearing organs. It is the symptom of reduced auditory sensitivity, synonymous with auditory impairment, when a specific cause can be ascribed. Also used, in a general sense, to describe the process of losing auditory sensitivity. Types of hearing loss are as follows:

a) Conductive: A hearing loss originating in the conductive mechanism of the ear;

b) Sensori-neural: A hearing loss originating in the cochlea or fibres of the auditory nerve. (Formerly called Perceptive Deafness).

c) Noise Induced: A sensori-neural hearing loss attributable to the effects of noise.

Hertz (Hz): Synonymous term for cycles per second. Most standardizing agencies have adopted hertz as the preferred unit of frequency.

I

Impact: A collision of one mass in motion with a second mass, which may be either in motion or at rest.

Impact Noise:
a) The noise resulting from the collision of two masses.
b) A sudden sound, resulting from two surfaces striking each other, characterized by high intensity, abrupt onset, rapid decay, and often rapidly changing spectral composition.

Impulse Noise: Impulse noises are usually considered to be singular noise pulses, each less than 1 second duration, or repetitive noise pulses occurring at greater than 1 second intervals. Also defined as a change of sound pressure of 40 dB or more within 0.5 second.

Intermittent Occupation Noise: Interrupted unwanted random sounds of brief duration repeated at intervals of greater than one second. This noise is usually produced by machines which operate for short, interrupted periods of time in an industrial environment.

Industrial Audiometry: The use of audiometric procedures in an industrial hearing-conservation program.

Industrial Elimination: An industrial elimination is widely used in the selection of industrial products for the elimination of judges whose performance is erratic.

Isolation: Isolation is a reduction in the capacity of a system to respond to an excitation, attained by the use of a resilient support.

Isolation, Sound: Materials or constructions which resist the passage of sound.

K

Kilohertz (kHz): 1000 Hz.

L

Leaks, Sound: Any opening which permits airborne sound transmission.

Logarithm: The logarithm of a number is the exponent or that power of a number to which another number, the base, must be raised to yield the number first named.
In symbols: $10^y = x$ $\log_{10} x = y$

M

Mean: The mean is a value such that the sum of deviations of observations from it is zero; it is thus the sum of the observations divided by their number:

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

where $_i$ is an observation or measurement, n the total number of observations, and $\overline{X}$ the mean.

Mezzocephalic Head: See Cephalic Index;

Microbar, dyne per square centimeter: A microbar is a unit of pressure commonly used in acoustics. One microbar is equal to 1 dyne per square centimeter.

N

N (newton): The base unit of force, mkg s^{-2}.

NIOSH: The National Institute for Occupational Safety and Health.

Noise: Noise is any undesired signal. By extension, noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device.

Noise Exposure: A generic term signifying the total acoustic stimulus applied to the ear over a period of time.

Noise Reduction Rating: A decrease of the sound pressure level at a specified observation point. Noise reduction is also used to designate the differences in sound pressure levels existing at two different locations at a single time, when the designated structures are in position. The method involves calculating the noise reduction that would be achieved by the use of the treatment as measured on an A-weighted sound level meter.

O

Octave: The interval between two sounds having a basic frequency ratio of two.

Octave Band: A division of the audible range of frequencies into sub-groups such that in each division the upper frequency limit is twice the lower limit. The centre frequencies used to designate the octaves are twice the centre frequency of the preceding octave band. One-third octave bands: a split of an octave band into three equal parts for more detailed analysis of distribution of sound energy.

Octave Band Analyzer: A device for measuring pressure levels of a sound for a frequency band corresponding to a specific octave.

Octave-Band Spectrum: See Spectrum.

Operator's Normal Position: The location of an operator with respect to a machine during the time it is operating. The position should be recorded for the particular machine installation.

OSHA: The Occupational Safety and Health Act (U.S.A.).

P

Pa (pascal): The base unit of pressure (Pa = N/m^2).

Pain, Threshold of: A sound pressure level sufficiently high to produce the sensation of pain in the human ear (usually above 120 dBA).

Period: The time required to complete one cycle; it is the reciprocal of the frequency.

Pink Noise: Noise whose spectrum level decreases with increasing frequency to yield constant energy per octave of bandwidth.

Population: The ensemble of values of a variable from which a sample is drawn.

Pressure Spectrum Level: The pressure spectrum level of a sound at a specified frequency is the effective sound pressure level for the sound energy contained within a band 1 Hz wide, centred at the specified frequency. Ordinarily this has significance only for sound having a continuous distribution of energy within the frequency range under consideration. The reference pressure should be explicitly stated.

Pure Tone: A sound wave, the instantaneous sound pressure of which is a simple sinusoidal function of the time. Audibly, it is characterized by a singleness of pitch.

R

Raw Data: Essentially, complete data in the time domain for a particular measurement without data reduction to de-emphasize unimportant or redundant detail or to provide a more useful mode of presentation.

Real-Ear Attenuation: The mean value (in decibels) of the occluded threshold (hearing protector in place) of audibility minus the open threshold of audibility (ears open and uncovered) for all listeners on all trials under otherwise identical test conditions.

Receiver: The affected person or equipment.

Reflection: The return from surfaces of sound energy not absorbed upon contact with the surfaces.

Reverberation: The persistence of sound in an enclosed space, as a result of multiple reflections after the sound source has stopped.

Reverberation Chamber: An enclosure in which all the surfaces have been made as sound reflective as possible. Reverberation chambers are used for certain acoustical measurements.

S

Sensitivity: The sensitivity of a receiving transducer is the ratio of its electrical output to its mechanical input.

Signal: A signal is a disturbance used to convey information.

Slow Response: A selectable mode of operation of a sound level meter or analyzer in which the indicator has high damping and therefore slowly responds to change in sound level. This mode tends to provide an average reading.

Sound: The auditory sensation produced through the organs of hearing, usually by vibrations transmitted in a material medium, commonly air.

Sound Absorption: The change of sound energy into some other form, usually heat, in passing through a medium or on striking a surface. In addition, sound absorption is the property possessed by materials and objects, including air, of absorbing sound energy. See also Attenuation.

Sound Insulation: The degree by which sound transmission is reduced by means of sound insulating structures and materials.

Sound Level: A-weighted value of sound pressure level as determined with a sound level meter.

Sound Level Meter: A device to measure sound level or weighted sound level, constructed in accordance with the standard specifications for sound level meters set up by the American National Standards Institute (ANSI). The sound level meter consists of a microphone, an amplifier to raise the microphone output to useful levels, a calibrated attenuator to adjust the amplification to values appropriate to the sound levels being measured, and an instrument to indicate the measured sound level; optional weighting networks are included to adjust the overall frequency characteristic of the response.

Sound Pressure Level (SPL): The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to the reference pressure. The reference pressure shall be explicitly stated. The following referenced pressures are in common use: (a) 0.0002 microbar, or (b) 1 microbar. Reference pressure (a) is in general use for measurements concerned with hearing and with sound in air, while (b) has gained widespread acceptance for calibration of transducers and various kinds of sound measurements in liquids.

Sound Waves: Vibratory motion caused by a vibrating body which transmits a series of alternating compressions and rarefactions (expansions) of the elastic medium.

Spectrum: Spectrum is used to signify a continuous range of components, usually wide in extent, within which waves have some specified common characteristics; for example, audiofrequency spectrum.
Octave-band spectrum: The ensemble of octave-band pressure levels comprising a sound. The audible spectrum is conventionally taken to embrace eight octaves. See also Octave-band.
1/3 Octave-band spectrum: The ensemble of band-pressure levels in bands 1/3 octave wide comprising a sound.

Spectrum Level: The spectrum level of a specified signal at a particular frequency is the level of that part of the signal contained within a band 1 Hz wide, centred at the particular frequency. Ordinarily this has significance only for a signal having a continuous distribution of components within the frequency range under consideration. The words "spectrum level" cannot be used alone, but must appear in combination with a prefatory modifier, such as pressure, velocity, voltage;

Standard Deviation: A numerical indication of the scatter of values of a variable around their mean (symbol σ). Specifically, it is the square root of the mean squared deviation, given by:

$$\sigma = \sqrt{\frac{\Sigma d^2}{n - 1}}$$

where d is the difference between the grand mean and an individual observation and n is the number of observations. In a normal distribution, a range of two standard deviations on each side of the mean will include 95.45 percent of all values, and three standard deviations on each side of the mean, 99.73 percent.
When the standard deviation is determined from a sample of values and not from the parent population (which is frequently unknown), the denominator within the square root should be taken in n - 1, due to the fact that one degree of freedom out of the total n is used to estimate the mean value x.

Standard Error: Standard error of the mean of a sample. The standard error is found by dividing the standard deviation of the items in the sample by the square root of their number. The mean of the population from which the sample was obtained is not likely to differ from the sample mean by more than plus or minus twice the standard error.

T

Temporary Threshold Shift (TTS): The component of threshold shift which shows progressive reduction with the passage of time when the apparent cause has been removed. The temporary hearing loss suffered as the result of noise exposure, if all or part of the loss is recovered during an arbitrary period of time when one is no longer subjected to the noise.

Tone: a) A sound wave capable of exciting an auditory sensation having pitch.
b) A sound sensation having pitch. See Pure Tone.

Transmission: The propagation of a vibration through various media.

Transmission Loss:
a) The difference between the noise level outside the ear muff and inside the ear muff.
b) The ratio, expressed in decibels, of the sound energy incident on a structure to the sound energy which is transmitted. The term is applied both to building structures (walls, floors, etc.) and to air passages (muff, muffler, ducts, etc.).
Transmission loss is the reduction in the magnitude of some characteristic of a signal, between two stated points in a transmission system. The characteristic is often some kind of level, such as power level; in acoustics the characteristic that is commonly measured is sound pressure level. Thus, if the levels are expressed in decibels, the transmission level loss is likewise in decibels.

V

Vibration: Vibration is an oscillation wherein the quantity is a parameter that defines the motion of a mechanical system.

W

Weighting Network: An electrical network designed to be incorporated in a sound level meter such that the latter conforms to a specified weighting curve. The three networks are designated A, B, and C, according to ANSI S1.4-1971.

White Noise: A noise whose spectral density (or spectrum level) is substantially independent of frequency over a specified range. White noise need not be random.

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Laboratory attenuation of ear muffs used in mines

1978

ESSAIS D'ATTÉNUATION AU LABORATOIRE AVEC DES CASQUES ANTIBRUIT UTILISÉS DANS LES MINES

par

M. Savich*

RÉSUMÉ

Les résultats détaillés de l'étude théorique et expérimentale menée au laboratoire avec onze casques antibruit disponibles dans le commerce montrent que les relations entre la force de serrage (force du serre-tête) et l'atténuation ne sont pas encore éclaircies. Les principales caractéristiques des casques antibruit ont été étudiées par :

1) une méthode psycho-physique
2) une méthode physique

Nous avons observé les effets suivants :

- la taille de la tête influe considérablement sur l'atténuation en raison de la différence dans la force de serrage;
- la quantité de cheveux emprisonnés entre les coussinets et la tête a un effet important sur l'atténuation par le casque antibruit;
- l'atténuation diminue lorsqu'on utilise des lunettes avec leurs adapteurs. Les adapteurs ne constituent pas des barrières efficaces;

Mots-clés : Casque antibruit, force de serrage, atténuation, mines.

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- on n'observe pas de grande différence dans l'atténuation lorsque le cou bouge;
- les casques antibruit de diverses marques n'ont pas la même efficacité;
- les casques antibruit dont la surface des coussinets est petite deviennent efficaces plus rapidement car la force par unité de surface est plus grande;
- une force de serrage supérieure à 900 (g pds), dans les princpaux casques antibruit, ne se traduit pas par une plus grande atténuation;
- il existe une certaine coïncidence entre les caractéristiques d'atténuation (ANSI Z24,22 - 1957) des casques antibruit et les essais physiques.

Les essais au laboratoire montrent une différence d'atténuation entre les casques ainsi qu'une différence entre les caractéristiques d'atténuation données par le fabricant (ANSI Z 24,22-1957) et les résultats des essais au laboratoire. Les meilleurs résultats ont été obtenus avec le casque n° 10, modèle J.

LABORATORY ATTENUATION TESTS OF EAR MUFFS USED IN MINES

by

M. Savich*

ABSTRACT

Detailed analysis of the theoretical and experimental solutions of eleven commercially available ear muffs in the laboratory showed that the relationships between clamping force (head band force) and attenuation remained unsolved. The main characteristics of ear muffs were investigated and analyzed by:

1) Psychophysical method, and
2) Physical method.

These investigations showed the following effects:

- head size has significant influence on the attenuation because of a different clamping force;
- test showed that the amount of hair trapped between the ear muff cushion and the head had a significant effect on ear muff attenuation;
- with the use of glasses and their adapters, attenuation decreases. The adapters are not effective barriers;
- there are no great differences in attenuation when the neck moves;
- the efficiencies of various brands of ear muffs are not equal;
- ear muffs with a small cushion area start serving their purpose more

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Key words: Ear Muff, Clamping Force, Attenuation, Mines.

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quickly because the force per area is larger;

- a clamping force larger than 900 (g wt) in the main ear muffs does not cause an increase in attenuation; and
- attenuation characteristics (ANSI Z24. 22 - 1957) of ear muffs show some coincidence with physical tests.

Laboratory tests showed that a difference in attenuation between muffs, and a difference between attenuation characteristics from factory (ANSI Z 24. 22-1957) and laboratory tests, exists. The best results were shown by the No. 10 Ear Muff, model J.

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Vignette

1. INTRODUCTION

Today, in Canadian mines, ear muffs are a part of safety equipment, and because of this a research study was conducted to investigate the efficiency of ear muffs.

Measurements of ear muff attenuations have been made using two methods:

1. Psychophysical method using human heads by static range-of-movement:
   a) Movement of the joint of the neck in normal position. Subject used glasses and adaptors.
   b) Movement of the joint of the neck, flexion, (dorsal and ventral) and neck rotation (right and left). Subject used glasses.
2. Physical method using apparatus for determining the efficiency of cup cushions.

These tests were made to provide performance data for eleven models of ear muffs under testing procedures established in the Elliot Lake Laboratory (Table 1 and 2):

No. 1.	Model A:	often used in mills and workshops;
No. 2.	Model B:	is used in mines, but is no longer in production;
No. 3.	Model C:	is used in workshops and mines;
No. 4.	Model D:	is used in mines;
No. 5.	Model E:	is used in mines;
No. 6.	Model F:	is used in mines and mills;
No. 7.	Model G:	is used when helmets are not required;
No. 8.	Model H:	is used mainly in workshops and open-pits when mounted

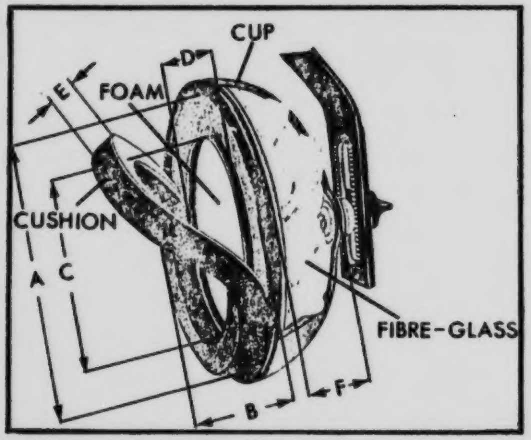


TABLE 1

Technical Data of Ear Muffs Acquired for Testing

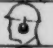
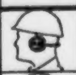
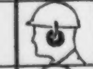
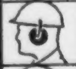
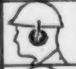
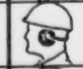
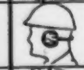
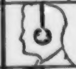
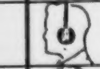
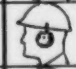
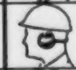
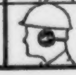
No.	Ear Muff	Filled Cushion	Band	Cross-sectional Dimensions (cm)						Area of Cushion (cm²)	Volume of Cup (cm³)	Weight (g)					Total Weight of Ear Muff (g)
				A	B	C	D	E	F			Cup	Cushion	Foam	Fibre-Glass	Σ wt	
1	A	Foam		9.7	9.7	6.5	4.3	1.1	4.2	48.0	180	49.86	13.67	7.61	-	71.14	185
2	B	Foam and air		9.5	9.5	6.5	4.2	0.8	4.8	40.0	159	73.45	11.44	3.90	-	88.79	234
3	C	Foam		10.7	8.0	6.7	4.0	1.0	3.6	35.6	117	51.13	5.79	0.59	2.46	59.97	188
4	D	Foam		10.5	8.0	6.8	4.1	0.9	3.8	28.5	131	45.30	4.49	1.11	-	50.90	182
5	E	Foam		10.6	8.0	6.8	4.2	1.0	3.8	28.0	131	42.80	4.43	1.27	-	48.50	151
6	F	Foam		9.8	8.3	6.5	3.9	1.0	4.5	43.1	158	63.40	10.47	8.07	-	81.94	291
7	G	Fluid		11.0	8.3	6.3	3.6	0.7	4.4	38.7	167	68.64	56.29	2.90	-	127.83	335
8	H	Foam		11.0	8.3	6.4	3.7	0.8	4.4	42.5	164	57.02	19.87	4.91	-	81.80	274
9	I	Foam		9.4	6.9	6.9	4.6	1.0	4.4	26.7	171	73.94	8.92	3.21	-	86.07	278
10	J	Foam		9.4	6.9	6.9	4.6	0.9	4.4	24.5	171	76.26	9.05	3.34	-	88.65	275
11	K	Foam		11.0	8.2	6.5	4.2	1.0	3.6	42.2	141	52.92	15.92	2.48	-	71.32	295
Σ	Arithmetic Mean of all Ear Muffs			10.24	8.2	6.62	4.13	0.93	4.17	36.16	153.6	59.50	14.58	3.58	2.46	80.12	248
	Std. Dev.			0.68	0.86	0.21	0.32	0.12	0.4	7.98	20.4	12.16	14.63	2.46	-	29.25	60.5

TABLE 2

Attenuation Characteristics of Ear Muffs Acquired for Testing

No.	Ear Muff	Band	Attenuation (dB)*									
			Characteristic	Frequency in Hertz								
				125	250	500	1k	2k	3k	4k	6k	8k
1	A		Measured	9.7	16.1	24.9	33.9	34.1	36.0	41.0	33.8	31.5
			Std. Dev.	3.2	2.5	2.8	5.1	2.9	5.6	5.7	6.6	5.9
2	B		Measured	5	13	22	31	31	41	36	28	21
			Std. Dev.	-	-	-	-	-	-	-	-	-
3	C		Measured	10	16	30	34	37	41	45	39	34
			Std. Dev.	-	-	-	-	-	-	-	-	-
4	D		Measured	11.5	16.5	26.5	36.5	38	38.5	44.5	39.5	-
			Std. Dev.	-	-	-	-	-	-	-	-	-
5	E		Measured	13.4	17.3	28.6	41.8	40.7	45.2	42.7	32.6	29.3
			Std. Dev.	3.3	3.9	3.0	3.4	5.6	4.6	5.3	4.1	4.7
6	F		Measured	17	18	29	36	38	44	44	43	43
			Std. Dev.	2.6	2.6	3.1	3.2	4.1	7.2	4.6	4.7	5.7
7	G		Measured	18	23	33	44	44	47	45	42	39
			Std. Dev.	-	-	-	-	-	-	-	-	-
8	H		Measured	18	23	33	44	44	47	45	42	39
			Std. Dev.	-	-	-	-	-	-	-	-	-
9	I		Measured	12	17	30	35	35	36	37	32	30
			Std. Dev.	2.5	3.0	4.6	5.6	4.5	4.3	4.2	4.1	2.9
10	J		Measured	10	17	28	37	36	44	39	32	30
			Std. Dev.	2.0	2.6	4.3	5.4	4.5	5.6	3.8	5.4	4.9
11	K		Measured	15	17	26	43	36	38	38	33	34
			Std. Dev.	5.2	3.9	8.8	3.6	4.9	6.6	6.8	1.3	5.3
Σ	Arithmetic Mean of all Ear Muffs			12.16	17.09	27.8	37.22	36.98	41.07	41.22	35.49	33.53
	Std. Dev.			3.86	2.47	3.09	4.31	3.58	3.9	3.49	5.0	7.36

* Attenuation characteristic measured in accordance with American National Standard Specification Z. 24. 22-1957 (from Factory Data).

on helmet;

No. 9. Model I: is used by the military, particularly the navy, and in workshops, very little used in mines;

No. 10. Model J: is used by the military, in workshops and in mines; and

No. 11. Model K: is used mainly by industry and in mines.

2. PSYCHOPHYSICAL METHOD

The ear muff attenuations had been measured as a transmission loss; the difference between the noise level outside the ear muff (measured 0.1 m from the side of the head) and that inside the ear muff (1). These measurements were not in compliance with the American Standards Association's requirements (2) (3).

2.1. Equipment

A block diagram of the test equipment is shown in Fig. 1. The test signals were produced with a Brüel and Kjaer, random noise generator, type 1402. An acoustical mirror was used to obtain a constant sound level of the test signal. The high powered loudspeaker was placed 1 m from the subject, as shown in Fig. 1. Microphones were suspended at the subject's ear: one under the cup and one over the cup, 1.3 m above the floor, and located in the room's centre.

The basic system for measuring sound pressure levels with a sound level meter consists of the following (4):

1. Transducer:
    - a) The microphone over the cup was a 1 in. condenser microphone, type 4145, B and K.

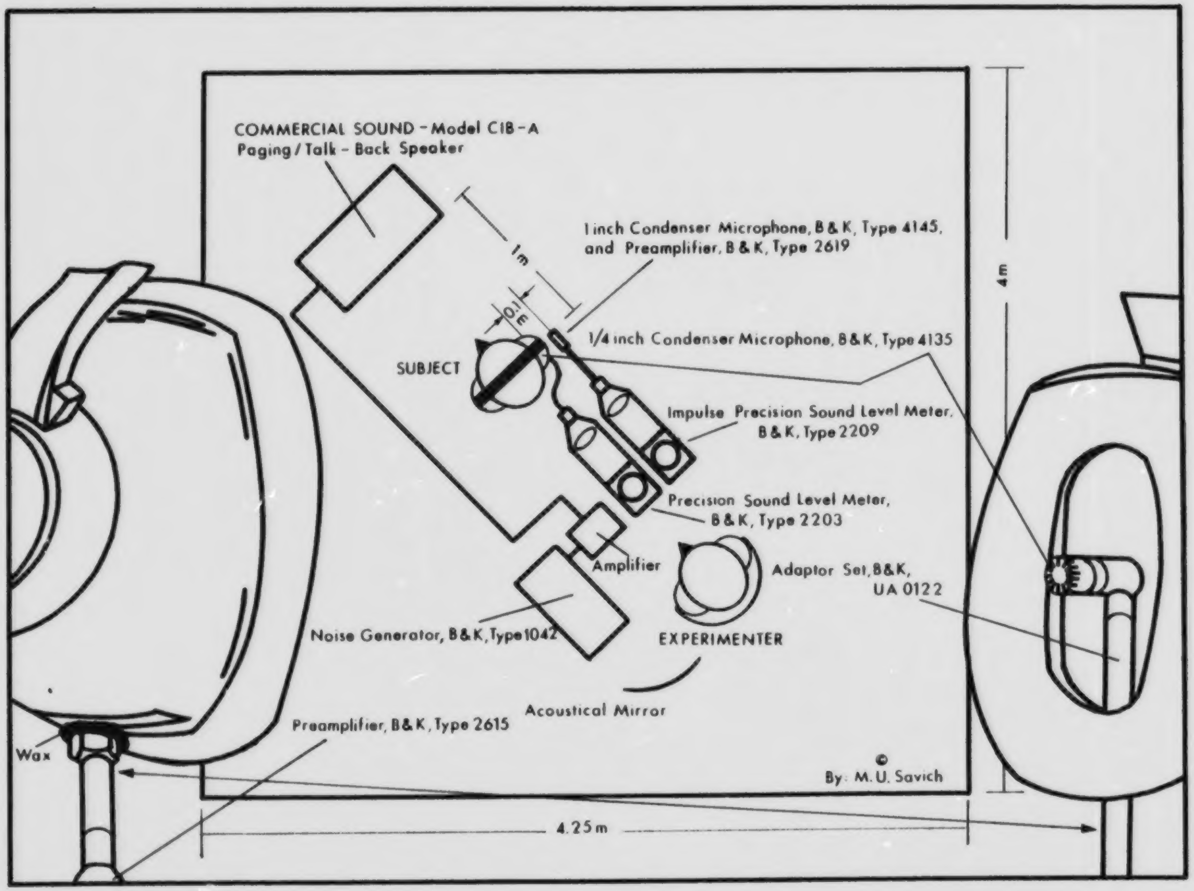

COMMERCIAL SOUND - Model CIB-A
Paging / Talk - Back Speaker
1m
0.1m
1 inch Condenser Microphone, B & K, Type 4145, and Preamplifier, B & K, Type 2619
1/4 inch Condenser Microphone, B & K, Type 4135
SUBJECT
Impulse Precision Sound Level Meter, B & K, Type 2209
Precision Sound Level Meter, B & K, Type 2203
Amplifier
Adaptor Set, B&K, UA 0122
Noise Generator, B & K, Type 1042
EXPERIMENTER
Acoustical Mirror
Preamplifier, B & K, Type 2615
Wax
© By: M. U. Savich
4m
4.25m

Fig. 1: Block diagram of experimental instruments for measuring the attenuation of ear muffs.

b) The microphone under the cup was a $\frac{1}{4}$ in. condenser microphone, type 4135, B and K.

2. Preamplifier:

   a) The preamplifier over the cup was a type 2619, B and K (IEC R 327 and ANSI S1.70 - 1966).

   b) The preamplifier under the cup was a type 2615, B and K (IEC R 327 and ANSI S 1.70 - 1966).

3. Sound level meter (IEC R 123 and ANSI S 1.4 - 1971):

   a) Impulse precision sound level meter, type 2209, B and K, which had the following: a frequency range of 2 Hz to 70 kHz; A, B, C and D weighting network, linear frequency response, and impulse measurement with max. R.M.S. hold (IEC R 179). An octave filter, type 1613, B and K was connected to an impulse precision sound level meter.

   b) A precision sound level meter, type 2203, B and K, which had a frequency range 10 Hz to 25 kHz; A, B, and C weighting network, and linear frequency response. An octave filter, type 1613, B and K, was connected to a precision sound level meter.

4. The calibrator was a pistonphone, type 4220, B and K, and the sound level calibrator was a type 4230, B and K.

5. Two head band (clamping force apparatus were developed in the Elliot Lake Laboratory. The apparatus are described in Appendix A-1 and A-2.

2.2. Subject Selection and Test Room

Two subjects for these tests were selected from the laboratory personnel. Subject 1 (age 35) with long hair, had a mezzocephalic head with a bizygomatic diameter of 13. 6 cm (significantly smaller than average), and subject 2 (age 54) short haired, had a brachycephalic head with a bizygomatic diameter of 16. 5 cm (significantly larger than average) (Fig. 2). In this case the human head replaced the dummy's.

The tests were conducted in a semi-reverberant room held at constant temperature, 4. 25 m long, 4 m wide and 2. 5 m high. The walls, ceiling and floor were constructed of wood and there was one window and one door in the room. The room was empty. Maximum ambient noise levels at the position of the subject (listener) were 35 dBA.

2. 3. Test Procedure Using Human Heads

Fitting Procedure: The process of fitting an ear protector is one of the most important factors affecting the sound attenuation characteristics of the device. Prior to the tests, each of the subjects was taught the correct fitting procedures for the eleven models. The device was first positioned by the experimenter and then it was positioned by the subject for a final orientation for each test. The general aim of the test was to measure ear muff efficiency using only one measurement.

Attenuation Measurements: Measurements of variation in sound pressure levels for a constant test signal level were made on both the left and right sides of the head. The ear muff attenuation was determined at the following frequencies: 125, 250, 1000, 2000, 4000 and 8000 Hz and at the dBA weighting network. Average noise levels of test signals, and the noise reduction ratings for eleven ear muffs were made (Table 3). There are 7 tests on each of two

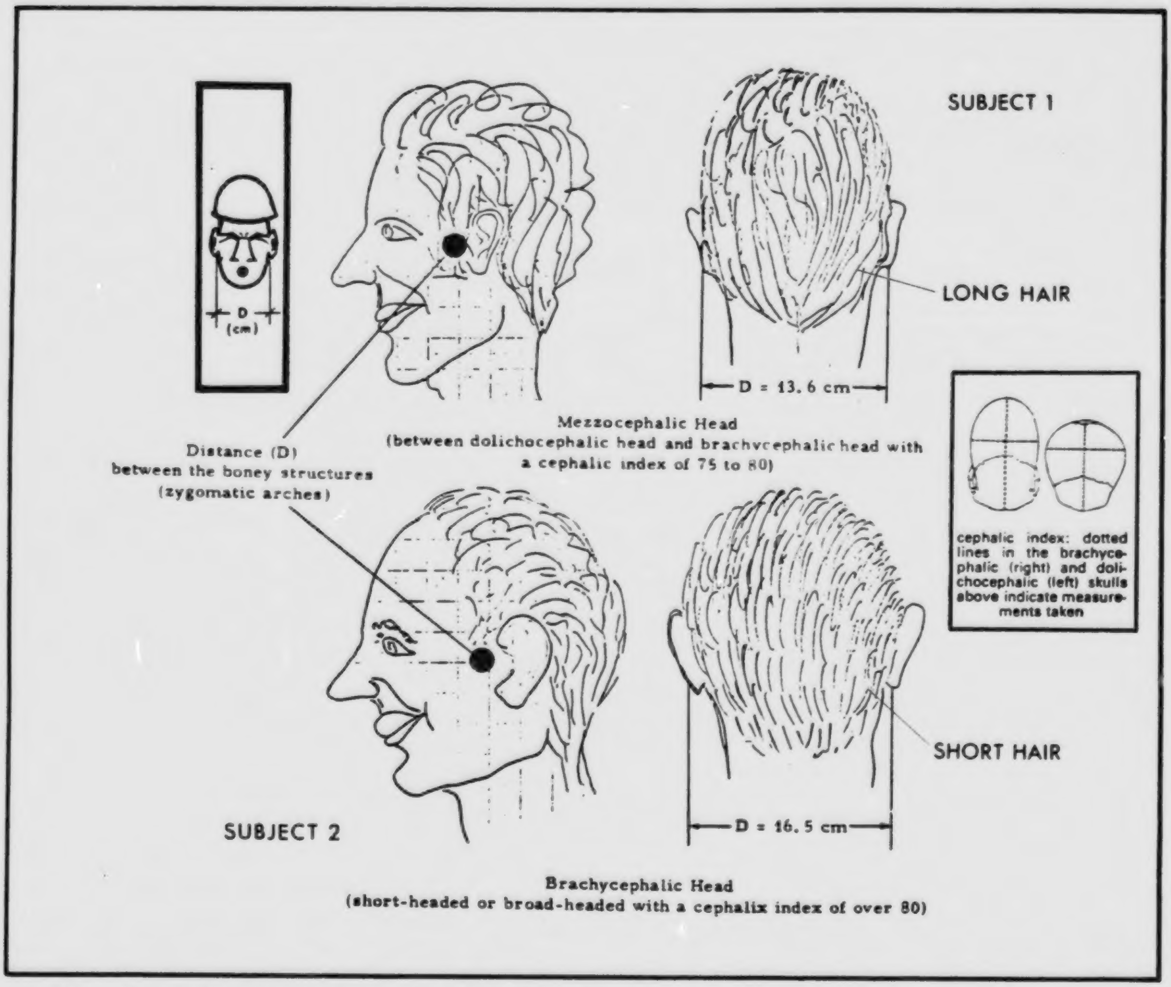

SUBJECT 1
LONG HAIR
D (cm)
D = 13.6 cm
Mezzocephalic Head
(between dolichocephalic head and brachycephalic head with a cephalic index of 75 to 80)
Distance (D) between the boney structures (zygomatic arches)
cephalic index: dotted lines in the brachycephalic (right) and dolichocephalic (left) skulls above indicate measurements taken
SHORT HAIR
SUBJECT 2
D = 16.5 cm
Brachycephalic Head
(short-headed or broad-headed with a cephalix index of over 80)

Fig. 2: Subjects for psychophysical tests.

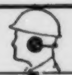
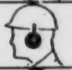
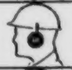
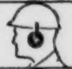
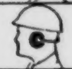
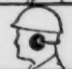
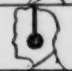
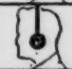
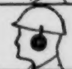
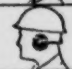
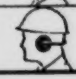
ears of each subject and 28 sets of measurements in all, except on one ear muff which had 4 extra tests.

2.4. Effect of Glasses and Adaptors on Attenuation of Ear Muffs

During this test the listener's neck joint was in normal position. The raw data of attenuation tests of ear muffs are summarized in a graph (with frequency in hertz) (Appendices C-1 to C-6) and in a table (dBA - network) (Appendix C-7). Total noise was estimated from the octave-band noise levels. Approximate agreement with the total noise measured

TABLE 3

Test Signals and the Noise Reduction Rating* of Ear Muffs during the Psychophysical Method of Measurement

No.	Ear Muff	Band	No. of Samples		Noise Level (dB) Frequency (Hz) 125	250	500	1000	2000	4000	8000	dBA	Reduction in dBA
1	A		28	Mean Std. Dev.	76.35 1.79	82.68 1.00	94.91 1.04	102.89 1.49	107.84 1.03	103.20 0.67	94.82 1.22	111.09	34.2
2	B		28	Mean Std. Dev.	74.25 0.78	79.32 0.48	91.41 1.05	98.89 1.15	103.86 1.05	100.36 1.25	91.95 1.28	107.44	31.1
3	C		28	Mean Std. Dev.	76.91 1.28	83.09 1.10	94.55 1.00	102.41 0.60	107.71 0.75	103.77 0.90	94.80 1.00	111.08	36.8
4	D		28	Mean Std. Dev.	74.60 0.55	79.48 0.40	91.89 0.84	99.09 0.79	104.91 0.99	100.21 0.99	92.80 1.53	108.06	37.5
5	E		28	Mean Std. Dev.	74.14 2.98	79.66 2.87	91.79 2.48	99.09 3.08	104.43 3.10	100.64 3.09	90.65 5.83	107.79	39.9
6	F		28	Mean Std. Dev.	76.89 0.35	82.91 0.89	94.32 0.97	102.00 0.81	107.86 0.86	103.36 0.72	95.39 1.00	111.07	38
7	G		32	Mean Std. Dev.	72.94 9.6	82.94 1.29	95.53 0.99	103.25 0.63	108.00 1.20	104.22 0.97	95.28 1.56	111.50	43.6
8	H		28	Mean Std. Dev.	76.88 1.30	83.06 1.24	94.16 3.92	102.34 0.47	108.57 1.10	103.41 1.10	95.89 1.59	111.57	43.6
9	I		28	Mean Std. Dev.	73.70 2.92	80.25 0.66	92.05 0.48	99.23 0.66	104.00 1.12	100.61 0.63	91.68 2.06	107.59	35
10	J		28	Mean Std. Dev.	77.05 0.87	82.07 1.14	95.07 0.86	102.64 1.41	107.59 0.79	103.61 0.96	95.14 1.05	111.01	36.3
11	K		28	Mean Std. Dev.	73.68 0.98	79.29 0.60	91.09 0.67	98.70 0.66	103.39 0.83	100.14 0.69	91.16 1.40	107.03	36.4
Σ-7	All Ear Muffs		10 (280)	Mean Std. Dev.	75.45 1.24	81.18 1.07	93.12 1.22	100.73 1.11	106.02 1.14	101.93 1.10	93.43 1.41	109.37	37.1
Σ	All Ear Muffs		11 (312)	Mean Std. Dev.	75.21 1.47	81.34 1.08	93.34 1.20	100.96 1.08	106.20 1.13	102.14 1.09	93.60 1.40	109.37	37

* Appendix B-1 Computer Program

indicates a reasonably constant condition during the period of measurement (Appendix B-2).

Measurements of ear muff attenuations were made in the current series of tests with: (a) ear muffs, (b) ear muffs and glasses, and (c) ear muffs, glasses and adapter. Muff/eyeglass adapters were specially designed for people wearing glasses in conjunction with hearing protectors (Fig. 3).

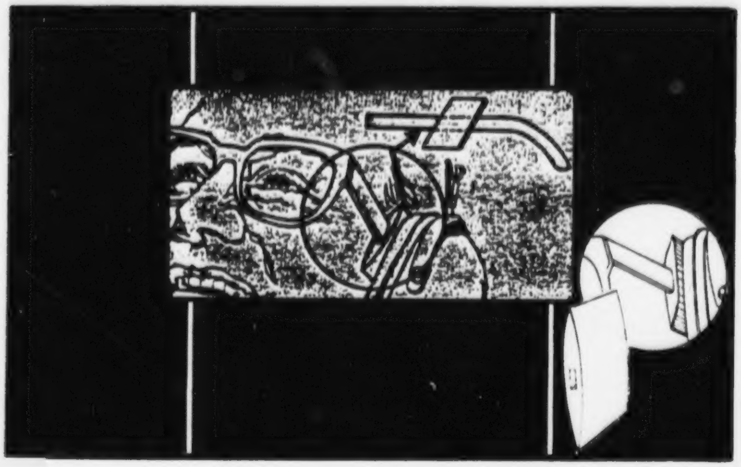


Fig. 3: Stop-gap/eye glass adapter (5).

It should be pointed out that at 125 Hz the attenuation is approximately 15 dB higher than normal. This was caused by distortion which is a change in transmitted sound that alters the character of the energy - frequency distribution within the signal so that the sound being received is not a faithful replica of the source sound.

The attenuation was observed in a semi-reverberant field with sound directed at the face. Differences in attenuation of 10 dB or more were observed over all frequencies (Appendices C-1 to C-6). The resulting differences in attenuation values over eleven ear muffs are found among subjects and between measurements on the same subject (Appendix C-4).

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On the same subject, left hemisphere versus right hemisphere attenuation differed. Probably for convenience and simplicity, the A-weighted sound level has become the most common single number rating for hearing damage risk. OSHA* legislation regarding noise pollution bases noise criteria on A-weighted sound levels in dBA (Table 4). Data reduction results were tabulated in dBA weighting network (Appendix C-7) so that better understanding and clearer presentation were possible. Data analyses in reduced form for estimation of the degree of environmental hazard were presented in the situation of the neck joint in normal position (Table 5). From the summary results in Table 5 the following can be concluded:

TABLE 4

Noise Exposure Limits for a Normal 8-Hour Working Day+

Band	Noise Level (dBA)	Maximum Exposure (h)
A	90	8
B	92	6
C	95	4
D	97	3
E	100	2
F	102	1.5
G	105	1
H	110	0.5
J	115	0.25
	Above 115	None

+ U.S. Code of Federal Regulations, Title 29, Section 1910.95.

1. Attenuation for subject 2 with large head and short hair is higher than attenuation for subject 1 with long hair, except in four measurements.
2. Ear muffs No. 3, No. 5, and No. 8 have almost equal attenuations for

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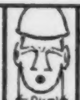
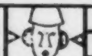
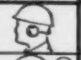
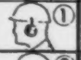
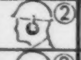
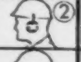
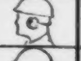
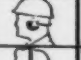
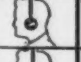
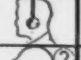
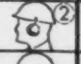
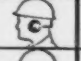
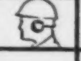
* The Occupational Safety and Health Act (U.S.A.)

TABLE 5

Attenuation Data Analysis in Reduced Form with the Neck Joint in Normal Position

No.	Ear Muff	Band	Subject	 D(cm)	 Clamping Force (g wt)	Attenuation (dBA) Muff Left Ear (L)	Right Ear (R)	L + R / 2	(L + R) /2 Difference	Average	Muff and Glasses Left Ear (L)	Right Ear (R)	L + R / 2	(L + R) /2 Difference	Average	Muff, Glasses and Adapter Left Ear (L)	Right Ear (R)	L + R / 2	(L + R) /2 Difference	Average	Summary L + R / 2	(L + R) /2 Difference	Average
1	A		1 2	13.6 16.5	580 780	28 34.25	28.5 28.25	28.25 31.25	+ 3	29.75	24.25 33.25	28 26.75	26.12 30	+ 3.88	28.06	18.5 32.25	26 19.25	22.25 25.75	+ 3.5	24	25.54 29	+ 3.46	27.27
2	B	 ①	1 2	13.6 16.5	1005 1355	29.75 37	31.5 31.5	30.62 34.25	+ 3.63	32.43	27 35	25.25 34	26.12 34.5	+ 8.48	30.31	24.5 29.5	21 30	22.75 29.75	+ 7	26.25	26.5 32.83	+ 6.33	29.66
3	C	 ②	1 2	13.6 16.5	730 930	26 30.5	31 28.25	28.5 29.37	+ 0.87	28.88	33 33	28 30	30.5 31.5	+ 1	31	31 32	26.25 31	28.62 31.5	+ 2.88	30.06	29.21 30.79	+ 1.58	30
4	D	 ②	1 2	13.6 16.5	980 1230	31.5 33.75	28.75 32.75	30.12 33.25	+ 3.13	31.68	30 31.5	25.75 30.25	27.87 30.87	+ 3	29.37	33 28.75	24 29.5	28.5 29.12	+ 0.62	28.56	28.83 31.08	+ 2.25	29.95
5	E		1 2	13.6 16.5	1980 2580	25 32.5	30.5 33.75	27.75 33.12	+ 5.37	30.43	36 32.5	30.5 33.75	33.25 33.12	- 0.13	33.18	32.25 29.25	30.75 31.75	31.5 30.21	- 1.29	30.85	30.83 32.12	+ 1.29	31.54
6	F		1 2	13.6 16.5	1180 1580	15.5 34.25	21.25 36.5	18.37 35.37	+ 17	26.87	14.25 33.25	20.5 33.5	17.37 33.37	+ 16	25.37	25.5 32.25	20.5 37.25	23 34.75	+ 11.75	28.87	19.58 34.5	+ 14.92	27.04
7	G		1 2	13.6 16.5	1230 1480	30.7 32.6	23.5 37.1	27.1 34.95	+ 7.85	31.02	30.4 34.1	17.4 34.4	23.9 34.25	+ 10.35	29.07	30.5 30.3	24.8 32.7	27.65 31.5	+ 3.85	29.57	26.21 33.56	+ 7.35	29.88
8	H		1 2	13.6 16.5	1130 1330	34 38.5	42.25 35	38.12 36.75	- 1.37	37.43	29.25 34.75	36 32.75	32.62 33.75	+ 1.13	33.18	31.25 32.5	37.25 33.75	34.25 33.12	- 1.13	33.68	35 34.54	- 0.46	34.77
9	I	 ②	1 2	13.6 16.5	730 1005	31.25 35.5	27 33	29.12 34.25	+ 5.13	31.68	29.25 37.75	28.25 33.75	28.75 35.75	+ 7	32.25	28.25 35.25	27 33.5	27.62 34.37	+ 6.75	30.99	28.5 34.79	+ 6.29	31.64
10	J		1 2	13.6 16.5	1330 1930	30.25 34.5	32.5 34.75	31.37 34.62	+ 3.25	32.99	29 33.75	31.75 34.5	30.37 34.12	+ 3.75	32.24	28.5 33	27 35.25	27.75 34.12	+ 6.37	30.93	29.83 34.29	+ 4.46	32.06
11	K		1 2	13.6 16.5	980 1280	23.5 28.25	27.25 31.5	25.37 29.87	+ 4.5	27.62	28 28.25	27 30	27.5 29.12	+ 1.62	28.31	24.5 27.75	25 26.5	24.75 27.12	+ 2.37	25.93	25.87 28.7	+ 2.83	27.29
1 - 11	Mean Std. Dev.	-	1	13.6	1077.7 377.9	27.77 5.13	29.45 5.44	28.61 4.72	+ (4.76 ± 2.23) Std. Error		28.22 5.44	27.13 5.08	27.67 4.44	+ (5.09 ± 2.06) Std. Error		27.98 4.36	26.32 4.60	27.15 3.75	+ (3.88 ± 0.94) Std. Error		27.81 3.86	+ (4.57 ± 1.92) Std. Error	
	Mean Std. Dev.	-	2	16.5	1407.3 502.3	33.78 2.84	32.96 2.97	33.37 2.32			33.37 2.35	32.15 2.52	32.76 2.09			31.16 2.23	30.95 4.86	31.03 2.97			32.38 2.22		
Σ	Mean Std. Dev.	-	1 & 2	-	1242.5 465.4	29.64 8.25	31.30 4.78	30.99 4.37		30.98 2.88	30.79 4.92	29.64 4.68	30.21 4.27		30.21 2.45	29.57 3.75	28.64 5.19	29.09 3.85		29.06 2.77	30.09 3.87		30.1 2.36

NOTE: ① Tested while mounted on helmet; B x 18A Safety Cap, CSA Standard Z 94.1

② Tested while mounted on helmet; Class C, CSA Standard Z 94.1

both subjects.

3. The largest attenuation difference for both subjects occurred with the No. 6 ear muff. This is because of the long hair worn by subject 1. The same thing occurred with ear muffs No. 2, 7, 9 and 10.
4. With the use of glasses and their adapters, attenuation decreases. The adapters are not effective barriers.
5. Efficiency of ear muffs is not equal:

Ear Muff No.	1	2	3	4	5	6	7	8	9	10	11
Noise Reduction* (dBA)	34.2	31.1	36.8	37.5	39.9	38	43.6	43.6	35	36.3	36.4
Attenuation** (dBA)	27.27	29.66	30	29.95	31.54	27.04	29.88	34.77	31.64	32.06	27.29
Difference (dBA)	6.93	1.44	6.8	7.55	8.36	10.96	13.72	8.83	3.36	4.24	9.11
Order of Performance✱	5	1	4	6	7	10	11	8	2	3	9

NOTE: * From Table 3
** From Table 5
✱ 1 = best; 11 = worst

Only No. 2 ear muff came close to the theoretical attenuation value. The largest attenuation was displayed by ear muff No. 8.

2.5. Effect of Movement of Joint of the Neck, Flexion and Neck Rotation, on Attenuation of Ear Muffs

This test was similar to the previous one. The objective of this test was to see the stability of ear muffs on heads in motion, and to measure air leaks when wearing glasses. Ear muff attenuation measurements were performed in four positions (using one measurement) (Fig. 4).

1. Neck flexion:

   a) Dorsal - head elevated,

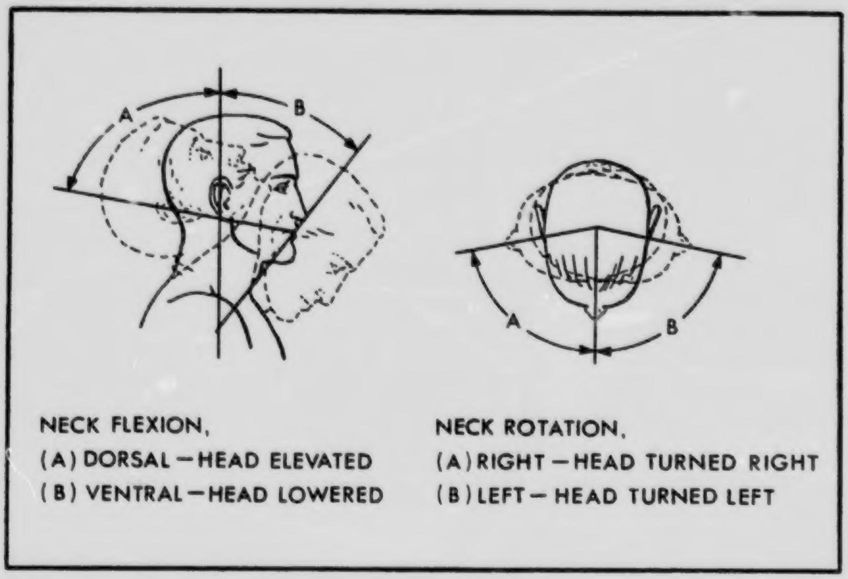

A
B
A
B
NECK FLEXION,
(A) DORSAL — HEAD ELEVATED
(B) VENTRAL — HEAD LOWERED
NECK ROTATION,
(A) RIGHT — HEAD TURNED RIGHT
(B) LEFT — HEAD TURNED LEFT

Fig. 4: Neck flexion and neck rotation.

b) Ventral - head lowered.

2. Neck rotation:

a) Right - head turned right,

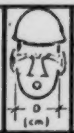
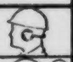
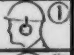
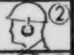
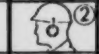
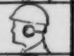
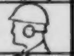
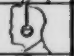
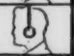
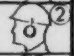
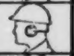
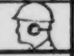
b) Left - head turned left.

Due to a lack of time, the left hemisphere was tested with glasses and the right hemisphere was tested without them. Raw data results were computed and are given in a graph (with frequency in hertz) (Appendices C-8 to C-12), and in a table (dBA-network) (Appendices C-13). Tests in Appendices C-8 to C-12 are similar to tests in Appendices C-1 to C-6, because these events were often repeated.

The analyses of environmental data were presented in reduced form, for some intended purpose, such as estimation of the degree of environmental hazards in a situation where the neck joint is flexed and the neck rotated (Table 6). From the results in Table 6 the following can be concluded:

TABLE 6

Attenuation Data Analysis in Reduced Form Where the Neck Joint is Flexed and the Neck Rotated

No.	Ear Muff	Band	Subject	 D (cm)	Clamping Force g wt	Attenuation (dBA)															
						Left Hemisphere with Glasses							Right Hemisphere without Glasses							Left and Right Hemispheres	
						Head elevated	Head lowered	Head turned right	Head turned left	Average	Difference	Total Average	Head elevated	Head lowered	Head turned right	Head turned left	Average	Difference	Total Average	Total Difference	Total Average
1	A		1 2	13.6 16.5	580 780	26.5 32.25	27 31.25	27.25 28.75	24.25 34.75	26.25 31.75	+ 5.5	29	30.5 31.75	29.25 32	32.5 35.25	27.25 29.25	29.87 32.06	+ 2.19	30.97	- 1.97	29.98
2	B	 ①	1 2	13.6 16.5	1005 1355	24.75 32.65	23.25 31.45	21 25	26.5 35.5	23.87 31.15	+ 7.28	27.51	27 31.5	32.25 33	29.25 33.5	25.25 32	28.44 32.5	+ 4.06	30.47	- 2.96	28.99
3	C	 ②	1 2	13.6 16.5	730 930	22 32.25	25.75 32.5	21.5 28.5	25 34	23.56 31.81	+ 8.25	27.69	28.75 30	32.25 34.75	29.75 36	30.25 33.5	30.25 33.56	+ 3.31	31.9	- 4.21	29.79
4	D	 ②	1 2	13.6 16.5	980 1230	28.25 34.5	32.75 30	29 30.5	35.5 36	31.37 32.75	+ 1.38	32.06	23.5 32.5	27.25 32	28.75 34.25	25.25 31.5	26.19* 32.56	+ 6.37	29.38	+ 2.68	30.72
5	E		1 2	13.6 16.5	1980 2580	22.75 28	26 28	27.25 27	30.5 30.25	26.62 28.31	+ 1.69	27.47	30.25 28.75	29.75 28	29.25 31.25	22.75 24.25	28 28.06	+ 0.06	28.03	- 0.56	27.88
6	F		1 2	13.6 16.5	1180 1580	19.75 32	14.25 34.5	13.5 29.25	19.5 35.25	16.75 32.75	+ 16	24.75	26 37	16.5 39.75	22.5 38.25	15.25 37.5	20.06 38.12	+ 18.06	29.09	- 4.34	26.92
7	G		1 2	13.6 16.5	1230 1480	- -	- -	- -	- -	- -	-	-	- -	- -	- -	- -	- -	-	-	-	-
8	H		1 2	13.6 16.5	1130 1330	28.75 36.5	28.25 35.75	27.75 38.75	30 34.75	28.69 36.44	+ 7.75	32.56	26.25 39.5	21.75 38.75	25 36.25	19.75 41.75	23.19 39.06	+ 15.87	31.13	+ 1.43	31.84
9	I	 ②	1 2	13.6 16.5	730 1005	24.75 32.75	27.5 29.5	23.25 29.25	30.75 35	26.56 31.62	+ 5.06	29.09	27.75 24.5	25.25 33.25	27 36.5	28 33	27 31.8	+ 4.8	29.41	- 0.32	29.25
10	J		1 2	13.6 16.5	1330 1930	32.25 33.75	33.5 33	35 33.5	33 37.5	33.44 34.31	+ 0.87	33.87	34.7 35.25	33.8 34.5	32.45 36.25	36.7 32.75	34.41 34.69	+ 0.28	34.55	- 0.68	34.21
11	K		1 2	13.6 16.5	980 1280	26.25 28.75	23.75 30.5	20 27	28.25 34.5	24.56 30.19	+ 5.63	27.37	28.5 32.5	27.5 32.75	30.75 34.25	26 33.5	28.19 33.25	+ 5.06	30.72	- 3.35	29.09
1 - 11	Mean Std. Dev.	-	1	13.6	1077.7 377.9	25.6 3.64	26.2 5.38	24.55 5.96	28.32 4.66	26.17 4.59	+ (5.94 ± 2.15) Std. Error	-	28.32 3.06	27.55 5.29	28.72 3.15	25.64 5.8	27.56 3.92	+ (6.01 ± 2.24) Std. Error	-	-	-
	Mean Std. Dev.	-	2	16.5	1407.3 502.3	32.34 2.50	31.64 2.35	29.75 3.89	34.74 1.85	32.11 2.21			32.32 4.25	33.87 3.40	34.17 3.29	32.9 4.61	33.57 3.16				
Σ	Mean Std. Dev.	-	1 & 2	-	1242.5 465.4	28.97 4.6	28.92 4.91	27.15 5.58	31.53 4.77	29.14 4.65	-	29.14 2.84	30.32 4.15	30.71 5.41	31.95 4.18	29.27 6.31	30.56 4.64	-	30.56 1.81	-	29.87 2.05

NOTE: ① Tested while mounted on helmet; B x 18A Safety Cap, CSA Standard Z 94.1

② Tested while mounted on helmet; Class C, CSA Standard Z 94.1

1. There are no great differences in attenuation when the neck moves;
2. The test performed on subject 1 (D = 13. 6 cm) showed that the amount of hair trapped between the ear muff cushion and the head had a significant effect on ear muff attenuation.
3. The largest difference in attenuation between two subjects is once again with the No. 6 ear muff (left side 16 dBA, and right side 18. 06 dBA).
4. The greatest attenuation occurred with the No. 10 ear muff on both subjects (34. 21 dBA).
5. On the average, with both subjects, glasses decreased attenuation by 1. 42 dBA.
6. The efficiency of ear muffs is not equal:

Ear Muff No.	1	2	3	4	5	6	7	8	9	10	11
Noise Reduction* (dBA)	34. 2	31. 1	36. 8	37. 5	39. 9	38	43. 6	43. 6	35	36. 3	34. 4
Attenuation** (dBA)	29. 98	28. 99	29. 79	30. 72	27. 88	26. 92	-	31. 84	29. 25	34. 21	29. 09
Difference (dBA)	4. 22	2. 11	7. 01	6. 78	12. 02	11. 08	-	11. 76	5. 75	2. 09	5. 31
Order of Performance✱	3	2	7	6	10	8	-	9	5	1	4

NOTE: * From Table 3
** From Table 6
✱ 1 = best; 10 = worst

Ear muffs No. 2 and No. 10 had the best efficiency with reference to the theoretical attenuation. Also ear muff No. 10 demonstrated the best attenuation of all ear muffs.

2. 6. Cushion Seals and Clamping Force

Manufacturers' specified attenuations were attained on ear muffs No. 2 and No. 10 only when worn on large head, subject 2. This was caused by an increase in clamping force and short hair. The hair length had the largest effect on ear muff attenuation even though this ear muff has cushion seals that retain softness. With the use of glasses and adapters attenuation decreased substantially on small as well as large heads. Eye-glass adapters do not have the characteristics attributed to them in the literature (6). The cause is simple: new materials for cushion seals perform the function of adapters.

Only ear muff No. 7 was tested twice to verify the efficiency of fluid-filled cushions (Appendix C-4). Cushion seal efficiency was very good. It should be mentioned that liquid-filled cushions can be designed so that they fail to give optimum attenuation (7).

Attenuation mainly depends upon two factors: clamping force and cushion seals. From Tables 5 and 6 it is evident that an increase in clamping force results in an increased attenuation.

3. PHYSICAL METHOD

Ear muff attenuation was measured as the difference between the outputs of the microphone uncovered and the cup covered microphone. For this test the apparatus to determine the efficiency of cup cushions under different clamping forces was made in the Elliot Lake Laboratory (Fig. 5).

3.1. Instrumentation

The sound field of a pure tone at 500 Hz, 1000 Hz, 3000 Hz and 8000 Hz, was generated by a Hewlett-Packard test oscillator, model 650A. A loud-speaker was placed 1 m from the centre of the apparatus taken in

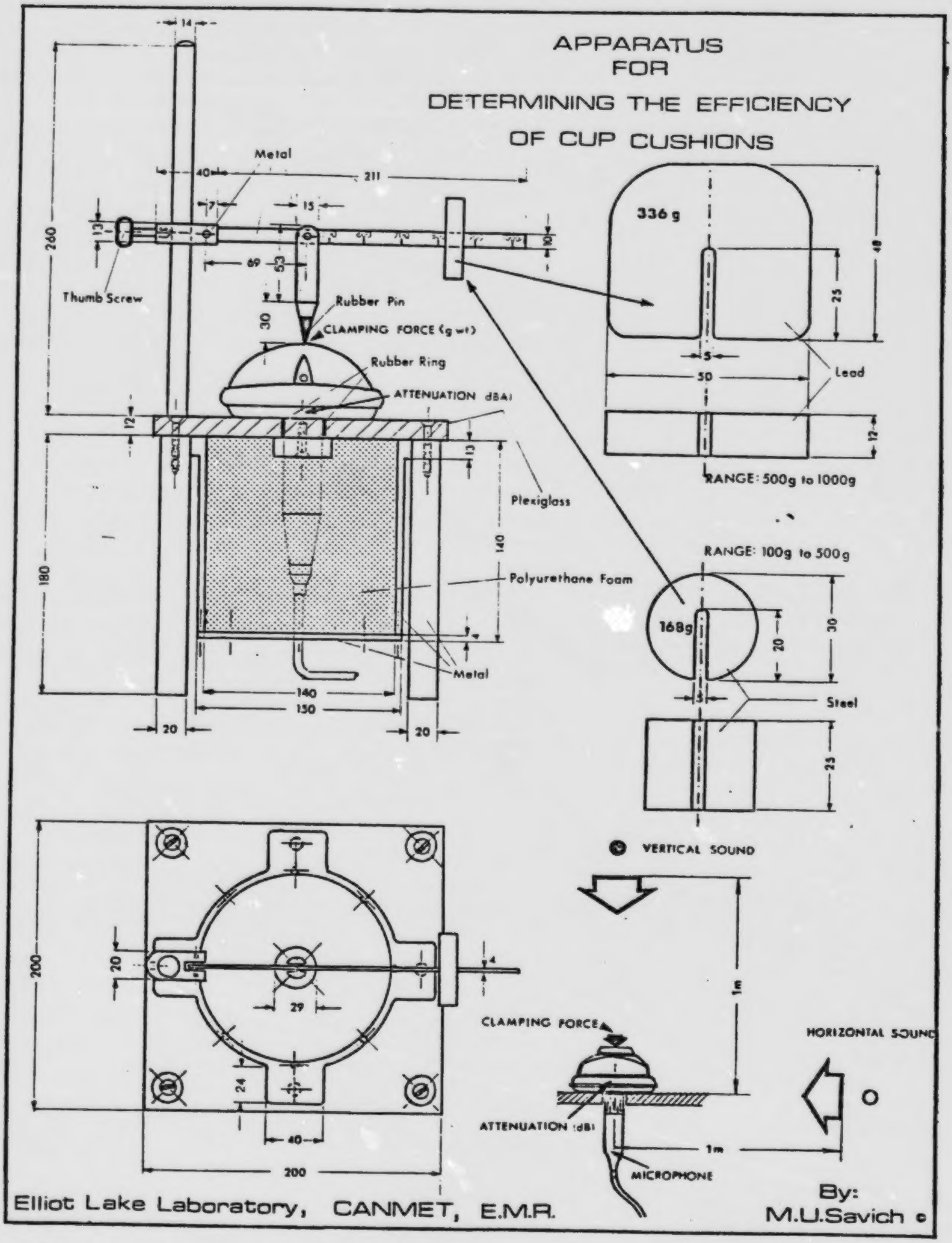

APPARATUS
FOR
DETERMINING THE EFFICIENCY
OF CUP CUSHIONS
14
260
Metal
40
211
7
15
13
10
69
53
Thumb Screw
Rubber Pin
30
CLAMPING FORCE (g wt)
Rubber Ring
ATTENUATION dBA
12
13
Plexiglass
180
140
Polyurethane Foam
Metal
140
150
20
20
336 g
48
25
5
50
Lead
12
RANGE: 500g to 1000g
RANGE: 100g to 500g
168g
30
20
5
Steel
25
200
20
29
4
24
40
200
VERTICAL SOUND
1m
CLAMPING FORCE
HORIZONTAL SOUND
ATTENUATION (dB)
1m
MICROPHONE
Elliot Lake Laboratory, CANMET, E.M.R.
By:
M.U.Savich ©

Fig. 5: Apparatus for determining the efficiency of cup cushions.

(Cont. overleaf)

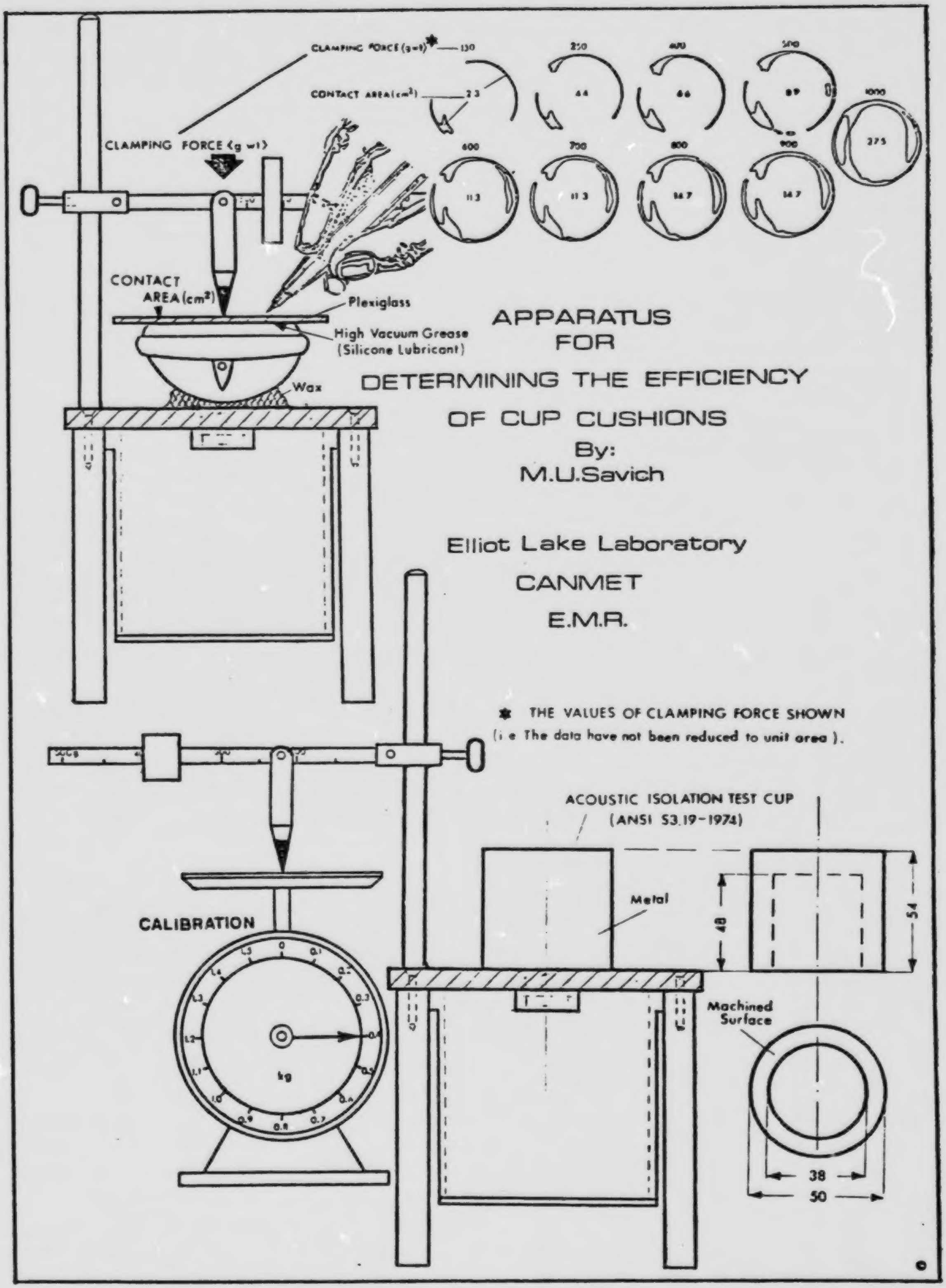

CLAMPING FORCE (g wt)* 130
CONTACT AREA (cm²) 2.3
250
4.4
400
6.6
500
8.9
1000
27.5
600
11.3
700
11.3
800
14.7
900
14.7
CLAMPING FORCE (g wt)
CONTACT AREA (cm²)
Plexiglass
High Vacuum Grease (Silicone Lubricant)
Wax
APPARATUS FOR DETERMINING THE EFFICIENCY OF CUP CUSHIONS
By: M.U.Savich
Elliot Lake Laboratory
CANMET
E.M.R.
* THE VALUES OF CLAMPING FORCE SHOWN (i.e. The data have not been reduced to unit area).
ACOUSTIC ISOLATION TEST CUP (ANSI S3.19-1974)
Metal
48
54
Machined Surface
38
50
CALIBRATION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
kg

Fig. 5. Cont.: Apparatus for determining the efficiency of cup cushions.

horizontal and vertical directions. A B and K microphone, type 4145, and a B and K preamplifier, type 2615 were placed in the apparatus to determine the efficiency of cup cushions. The measurements were observed by Brüel and Kjaer impulse precision sound level meter, type 2209, in the dBA weighting network. The reading made is taken to the sound level. The measuring system used was calibrated by the pistonphone, a Brüel and Kjaer type 4220, to measure band pressure level with reference to 20 μ Pa(Pa=N/m^2).

3. 2. Apparatus

The apparatus for determining the efficiency of cup cushions was constructed in accordance with the dimensions shown in Fig. 5. Both cups of an ear muff could have been tested on this apparatus separately, however, only one cup was tested because of lack of time.

Acoustical isolation of the apparatus was less than 60 dB in any test frequency band in the range of interest. A sample test cup is shown in Fig. 5 (ANSI S3. 19 - 1974).

3. 3. Test Procedure

The ear cup was spread and placed on the plane plexiglass surface. The steelyard's rubber pin was pressed against the ear cup and a clamping force was selected. Loss of attenuation by an ear cup under a constant clamping force and different pure tone test signal level was examined. These data demonstrate that the range of loss is approximately the same when ambient levels range from 80 dBA to 110 dBA. Output test signal data are presented in Table 7.

TABLE 7

Output Test Signal

No.	Ear Muff	Horizontal Sound in dBA						Vertical Sound in dBA					
		Pure Tone Test Signal at Selected Frequency (Hz)						Pure Tone Test Signal at Selected Frequency (Hz)					
		500	1000	2000	3000	4000	8000	500	1000	2000	3000	4000	8000
1	A	90	100	105	100	100	80	90	100	110	95	100	80
2	B	90	100	105	100	95	80	95	105	110	100	100	80
3	C	95	100	105	100	100	80	95	100	110	100	95	80
4	D	90	100	105	100	100	80	95	100	110	95	100	75
5	E	95	100	105	100	100	80	100	105	110	95	100	80
6	F	95	100	100	100	90	80	90	100	110	95	100	80
7	G	90	100	105	100	100	80	95	100	105	95	95	75
8	H	95	100	105	100	100	75	95	105	110	95	100	80
9	I	100	100	95	100	100	80	95	100	110	90	100	80
10	J	95	100	105	100	100	80	95	105	110	100	100	75
11	K	95	100	105	105	100	80	100	105	110	100	100	75
Σ	Mean	93.64	100	103.64	100.45	98.64	79.54	95.45	102.27	109.54	96.36	99.09	78.18
	Std. Dev.	3.23	0	3.23	1.51	3.23	1.51	2.70	2.61	1.51	3.23	2.02	2.52

3.4. Measurement

The sound pressure levels at the microphone were measured for the acoustic test field without an ear cup. Afterwards the hearing protector was placed over the microphone and the sound pressure levels were measured again. Readings are taken at the preferred centre frequency, and at the preferred clamping (head band) force. The measurements should be taken for right and left ear cups. When the measured difference between ear cups is 5 dB or greater, the attenuation of each ear cup should be reported (ANSI S3.19 - 1974).

When the No. 5 ear muff was tested, comparison of attenuation was made with and without a chamois cloth between ear cup and plexiglass (Fig. 6). No major differences between covered (with a chamois cloth) and uncovered plexiglass occurred. Only at 4 kHz (horizontal sound) are differences without a tolerance limit. Because of this, all tests were conducted without a chamois cloth.

3.5. Ear Muff Attenuation

The algebraic difference in sound pressure levels, in dBA weighting network, at each test frequency signal, with and without the ear cup in place on the plexiglass, is considered to be the attenuation of the device. The attenuation data and efficiency of cup cushions from eleven ear muffs were presented in graphic form (Appendix D).

For a discussion of results, the clamping force at 450 (g wt) for one cup was used as a basic level (ANSI S 3.19 - 1974). From the formula $F = b W/a$, used in the force measurement system, the clamping (head band)

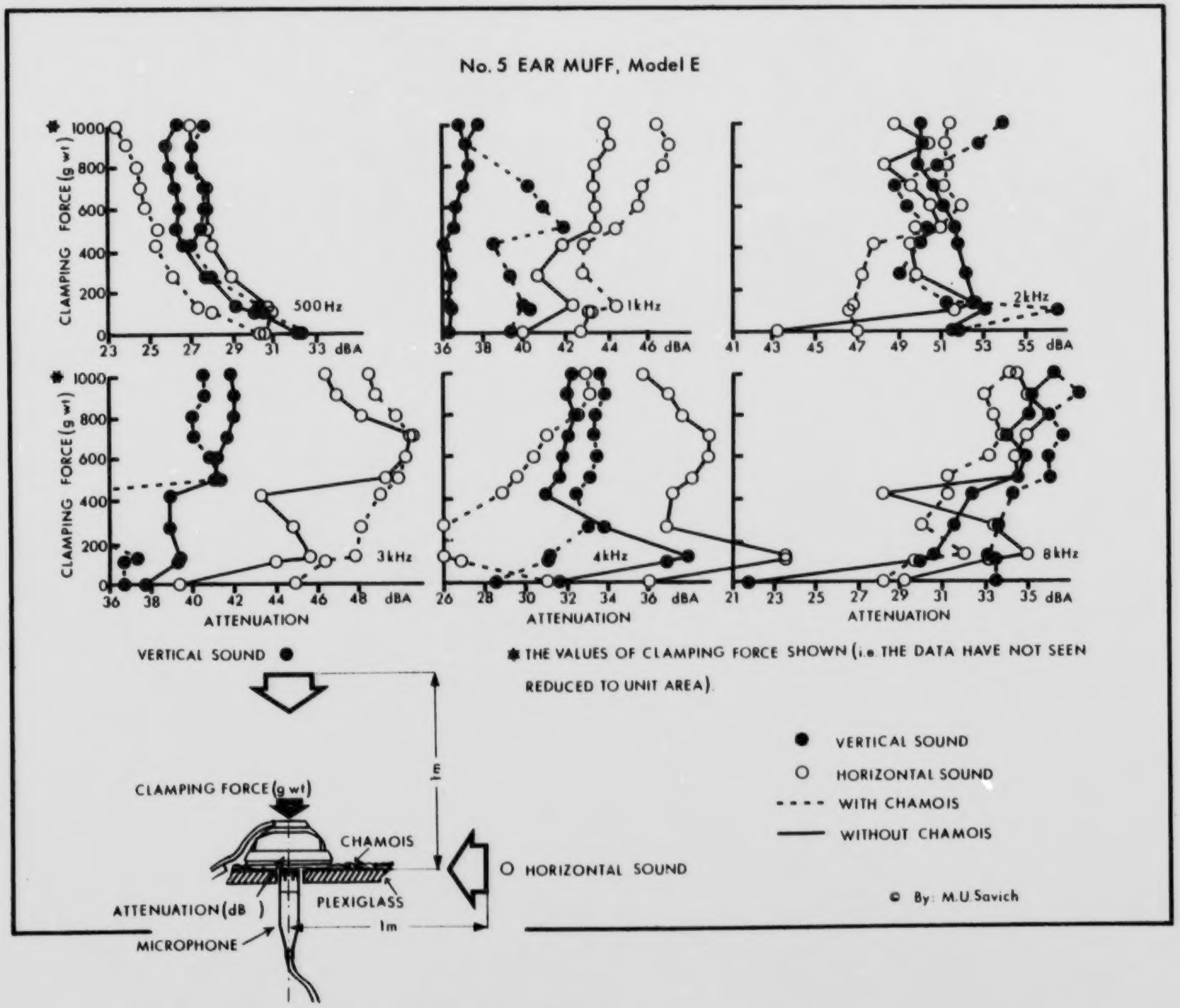


Fig. 6: Ear cup attenuations with and without a chamois cloth.

force will be 900 (g wt) if b = a (Appendix A-3). Also, attenuation characteristics measured in accordance with ANSI Z 24.22 - 1957 are included so as to be compared with the efficiency of cup cushions. All ear muffs should be divided into three main groups:

Group	Ear Muff	Force (g wt)	Attenuation Behaviour
1	No. 4, No. 5, No. 8, No. 9, and No. 10	150 to 350	Steady at all frequencies and clamping forces
2	No. 1, No. 3, and No. 6	350 to 550	Steady at some frequencies and clamping forces
3	No. 2, No. 7, and No. 11	> 550	Variable at all frequencies and clamping forces

In general, the attenuation values of ear cups are dependent upon two factors:

1. Clamping (head band) force (g wt), and
2. Design of the ear cup cushion.

Both factors were taken into consideration in this test. It is evident from the graphs (Appendix D) that attenuation is a function of amount of air leakage. An air leak causes different losses of attenuation at various frequency test signals as well as different losses among the various ear muffs.

A greater attenuation is obtained when an ear cup is exposed to horizontal sound, than when it is exposed to vertical sound (Table 8). According to acoustical laws, the opposite should be expected. E. A. G. Shaw came to the same conclusion and this phenomenon is yet to be explained (8).

From graphs in Appendix D, one can see developing a rudimentary theory to guide us in the design of ear muffs. Physical measurements of

TABLE 8

Attenuation of Ear Muffs with Horizontal and Vertical Test Signals

No.	Ear Muff	Horizontal Sound - Clamping Force 450 (g wt)						Vertical Sound - Clamping Force 450 (g wt)					
		Attenuation (dBA) of Pure Tone Test Signal at Selected Frequency (Hz)						Attenuation (dBA) of Pure Tone Test Signal at Selected Frequency (Hz)					
		500	1000	2000	3000	4000	8000	500	1000	2000	3000	4000	8000
1	A	27	34	50	46	48	35	28.5	31.5	45	37.5	42	35.5
2	B	8	27	28	31	23	27	15	27.5	22	28	27	18.5
3	C	25	36	46	37	43	34	28.5	33	44	40	41.5	31
4	D	21	40	45	49	35	24	25.5	39	55.5	39.5	29	32
5	E	28	43	50	46	37	29	26.5	36.5	52	40	31	33
6	F	21	31	41	46	32	37	29	37	49.5	40	37.5	29
7	G	26	45	50	39	36	34	31	41	56	28.5	40	28
8	H	33	42	47	46	39	25	34	45	43	39	45.5	31.5
9	I	35	45	32	35	45	33	35	43.5	42	23	36	29.5
10	J	33	45	43	47	45	35	37.5	46.5	44	32.5	39.5	33
11	K	29	37	51	46	27	30	38.5	42	46.5	36.5	26	21
Σ	Mean	26	38.64	43.91	42.54	37.27	31.18	29.91	38.41	45.41	34.95	35.91	29.27
	Std. Dev.	7.54	6.15	7.62	5.96	7.84	4.42	6.58	5.97	9.19	6.01	6.65	5.18

attenuation can provide valuable information.

This test explained the following:

1. Ear muffs with a small cushion area start serving their purpose more quickly because the force per square centimeter is larger;
2. A clamping force larger than 900 (g wt), in the first and second groups, does not cause an increase in attenuation;
3. Attenuation characteristics (ANSI Z24. 22 - 1957) of ear muffs show a coincidence with physical tests. They cannot be completely compared because their values differ, dB versus dBA.

Based on the extensive literature and the physical tests performed, apparatus for determining the efficiency of cup cushions can be used effectively to apply theory in the design of ear muffs.

4. CONCLUSIONS

Laboratory tests were done by using simplified methods and constructions, which were developed in the Elliot Lake Laboratory.

A series of eleven ear muffs were investigated and analyzed by:

1. Psychophysical method, and
2. Physical method.

The ear muff attenuation, by psychophysical method, had been measured as a transmission loss; the difference between the noise level outside the ear muff and that inside the ear muff (1). These measurements were not in compliance with the American Standards Association's requirements (ANSI Z 24. 22 - 1957 and ANSI S 3. 19 - 1974).

The tests were conducted in a semi-reverberant room using two subjects selected from the laboratory personnel (Fig. 2). Measurement of ear muff attenuations have been made using human heads by static range-of-movement:

a) Movement of the joint of neck in normal position. Subject used glasses and adapters.

b) Movement of the joint of the neck, flexion (dorsal and ventral) and neck rotation (right and left). Subject used glasses.

Ear muff attenuation, by the physical method, was measured as the difference between the outputs of the microphone uncovered and the cup covered microphone. For this test the apparatus to determine the efficiency of cup cushions under different clamping forces was made in the Elliot Lake Laboratory.

Laboratory tests showed that a difference in attenuation between muffs, and a difference between attenuation characteristics from factory (ANSI Z 24.22 - 1957) and laboratory tests, exists. From data obtained by using the physical method, it is possible to calculate with reasonable accuracy some psychophysical quantities that are related to the effect of noise reduction by ear muffs.

The best results were shown by the No. 10 Ear Muff, model J, (see pages 13, 16 and 24).

5. ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Mines Accident Prevention Association of Ontario for providing a selection of ear muffs for this project. He is also indebted to E.D. Dainty, Project Leader, CEAL; Dr. R. Tervo, Manager and G. Knight, research scientist, Elliot Lake Laboratory, who were helpful in many ways. Grateful acknowledgement is given to A. Webster who transcribed and completed the tables from the raw data. He acknowledges the contribution of R. Regan for his assistance in the laboratory work.

6. REFERENCES

1. Russell, M.F. and May, S.P. "Objective test for ear muffs"; J Sound and Vibration; vol. 44, No. 4; 1976.

2. American National Standards Institute; "Method for the measurement of the real-ear attenuation of ear protectors at threshold"; ANSI Z 24.22 - 1957.

3. American National Standards Institute; "Method for the measurement of real-ear protection of hearing protectors and physical attenuation of ear muffs"; ANSI S 3.19 - 1974.

4. Brüel and Kjaer; data from 1975 sales literature.

5. David Clark Company; data from 1976 sales literature.

6. Nixon, C.W. and Knoblack, W.C. "Hearing protection of ear muffs worn over eye-glasses"; Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio; AMRL-TR-74-61; 1974.

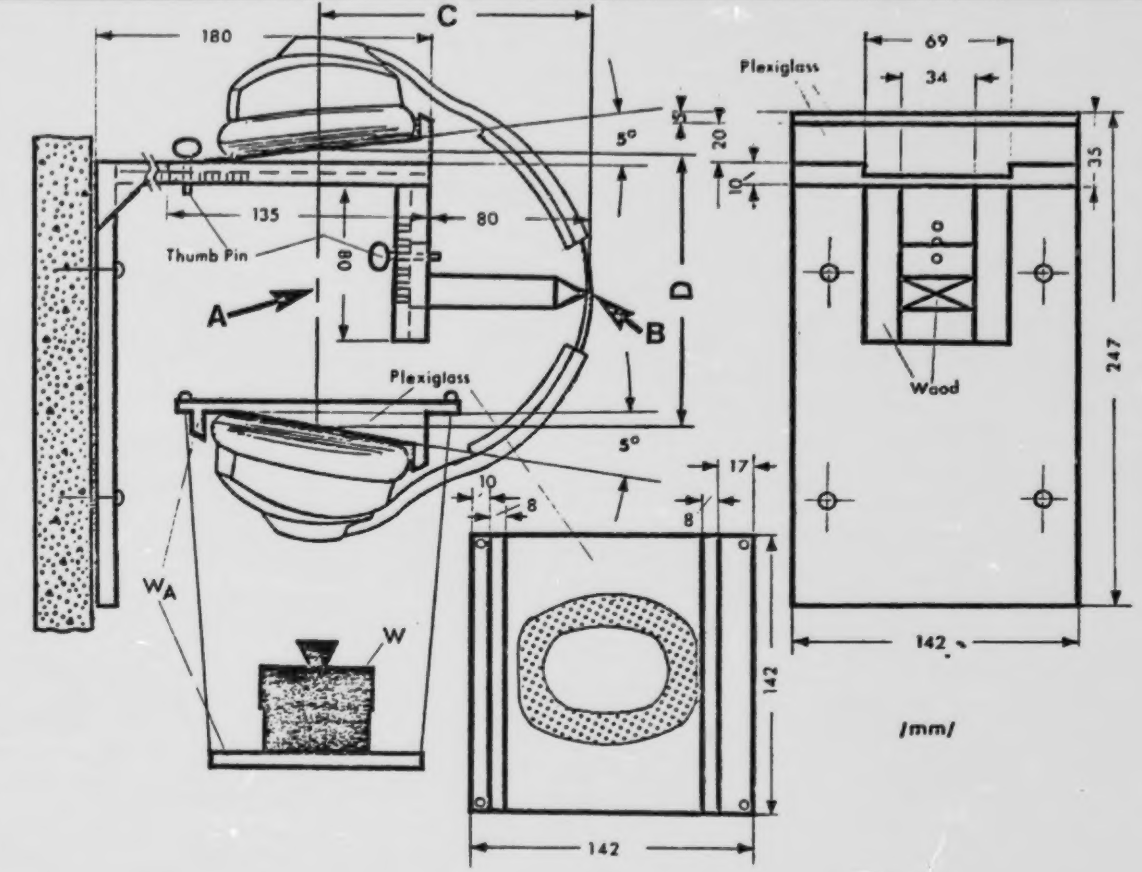
7. Shaw, E.A.G., and Thiessen, G.J. "Improved cushion for ear defenders"; J Acoust Soc Amer; vol 30; Jan 1958.

8. Shaw, E.A.G.; Private communication, 1977.

APPENDIX A

Force Measurement Systems

Headband Force Apparatus (Elliot Lake Laboratory)


C
180
69
34
Plexiglass
5°
15
20
10
35
135
80
Thumb Pin
80
A
B
D
247
Wood
Plexiglass
5°
17
10
8
8
W_A
W
142
142
142
/mm/

Clamping force measurement of ear muffs with headband.

NOTES:

1) A: Centreline passes through pivot point of earcup attachment to headband.
   B: After correct head band distance is obtained (operator's head size), move out of the way for force measurement.
   C: Correct operator's head size.
   D: Bizygomatic Diameter (D).

2) Construction: Almost any material can be used: wood, steel, plexiglass, etc.

3) Calibration: No calibration. When measuring, the attachment weight must be taken into account. Clamping force (g wt) = $W_A + W$ (where W_A is the attachment weight, and W is the weight).

4) Operation: As shown in Fig. above.

5) Accuracy: ± 10 g.

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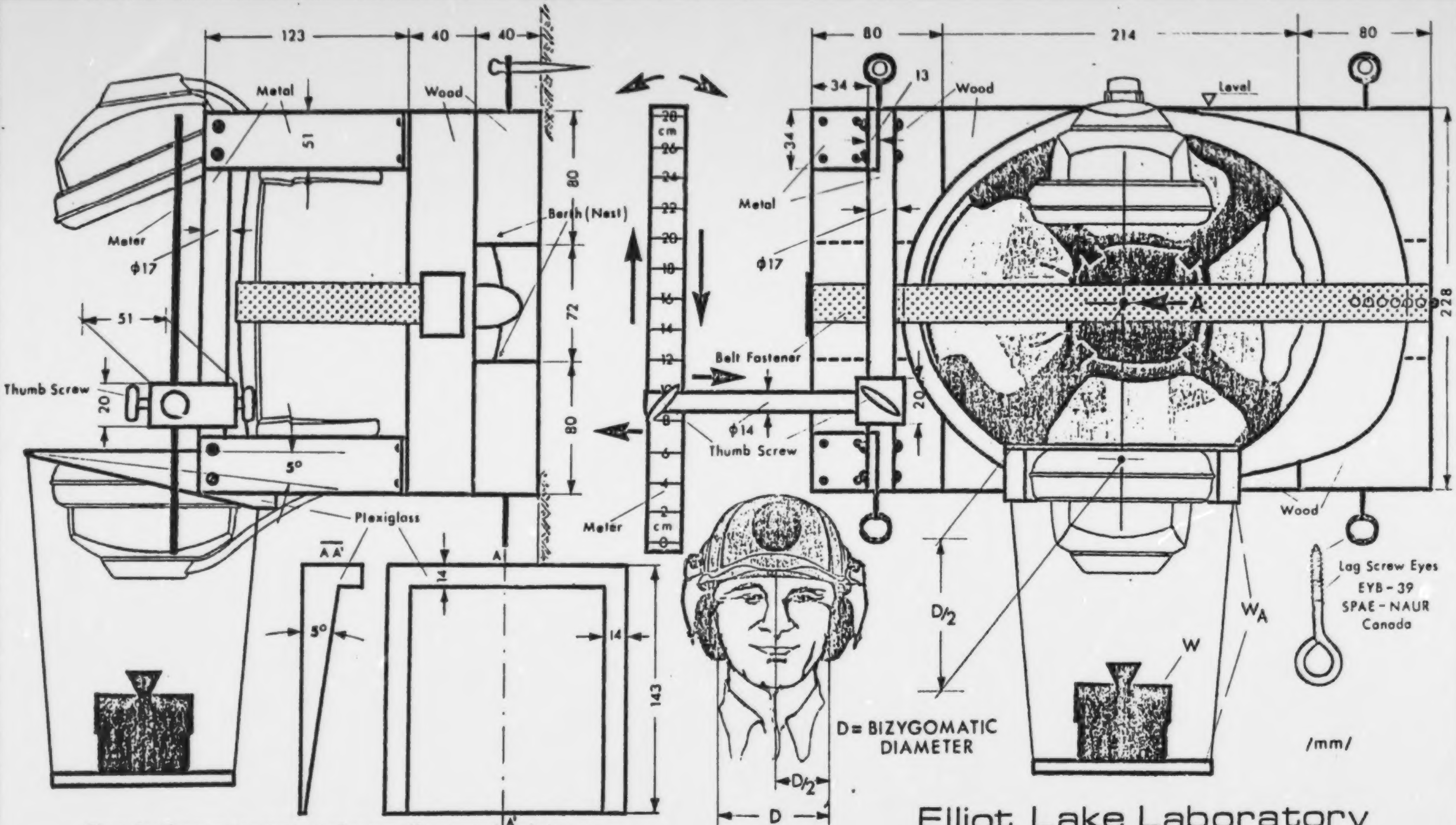
Apparatus for Clamping Force Measurements on Helmet (Elliot Lake Laboratory)


123
40
40
Metal
Wood
51
Meter
ϕ17
Berth (Nest)
80
72
80
51
Thumb Screw
20
5°
Plexiglass
$\overline{AA'}$
5°
A
A'
14
14
143
28 cm
26
24
22
20
18
16
14
12
10
8
6
4
2 cm
0
Meter
80
214
80
34
13
Wood
Level
34
Metal
ϕ17
Belt Fastener
ϕ14
Thumb Screw
20
A
228
Wood
D/2
W
W_A
Lag Screw Eyes
EYB-39
SPAE-NAUR
Canada
D = BIZYGOMATIC DIAMETER
D/2
D
/mm/

Clamping force measurement of ear muffs mounted on helmets.

NOTE:

1) A: Centreline passes through pivot point of ear cup attachment to hat (helmet).
2) Construction: Almost any material can be used: wood, steel, plexiglass etc.
3) Calibration: With lag screw eyes both edges of the apparatus are placed horizontally using a level. No calibration with weight.
4) Arrangement: The hat is placed on a berth (nest) lined with rubber and the belt fastener is well tightened.
5) Operation: Measurement should be done for one earcup first. The apparatus is then turned 180°, and measurement is done for the other cup. By this method, assymetry of clamping force can be measured. When measuring, the attachment weight must be taken into account. Clamping force (g wt) = $W_A + W$ (where: W_A is the attachment weight, and W is the weight).
6) Accuracy: ± 10 g.

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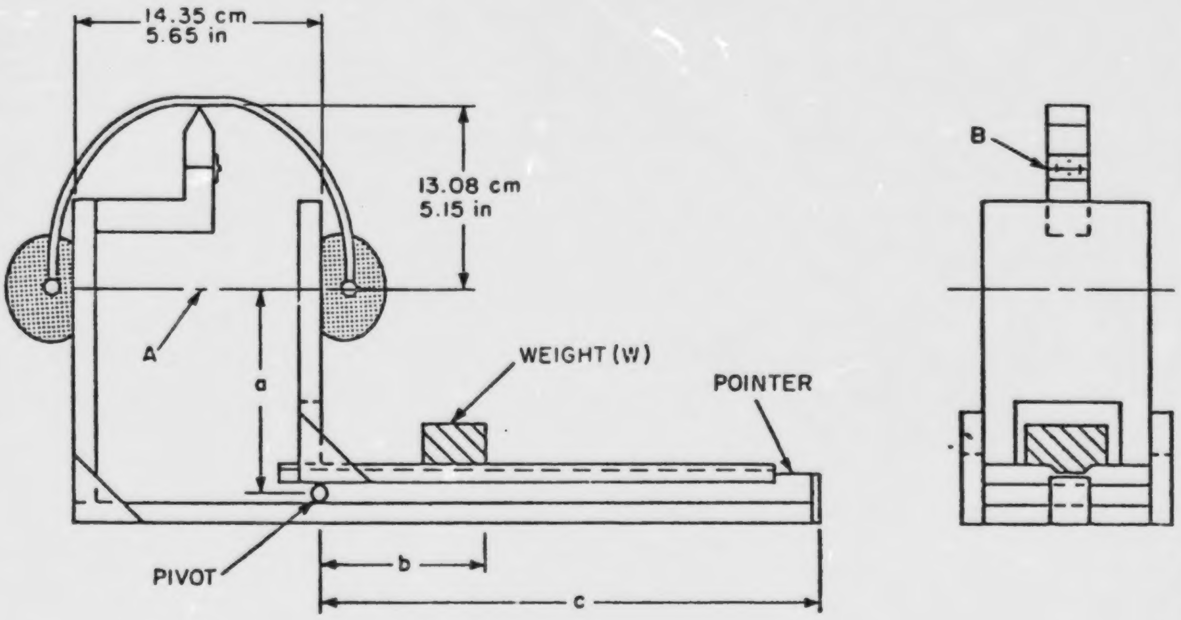
Headband Force Apparatus
(ANSI S 3. 19-1974)



Force measurement system.

NOTES:

(1) A: Centerline passes through pivot point of earcup attachment to headband.

(2) B: After correct headband distance is obtained, move out of way for force measurement.

(3) *Construction:* Almost any material can be used providing that the units are made sufficiently rigid. The only critical dimensions are the earcup separation distance (14.35 cm or 5.65 in.) and the headband extension distance (13.08 cm or 5.85 in.). For best results, dimension "a" should be 12.0 cm (4.72 in.) to 15.0 cm (5.90 in.) and dimension "c" should be 30.5 cm (12 in.). A good free-working hinge with a small center pin is satisfactory as the pivot point. Weight is recommended to be about 900 g (about 2 lb).

(4) *Calibration:* With the pointer aligned, the distance between the two faces must be read 14.35 cm ± 0.2 cm. If the construction is such that the weight can be moved over the pivot point, then the zero force location is found by positioning the weight where it just balances. The force (*F*) at any location at a distance *b* that the weight has moved from the zero point is found by $F=bW/a$. A scale of grams (pounds) can be marked.

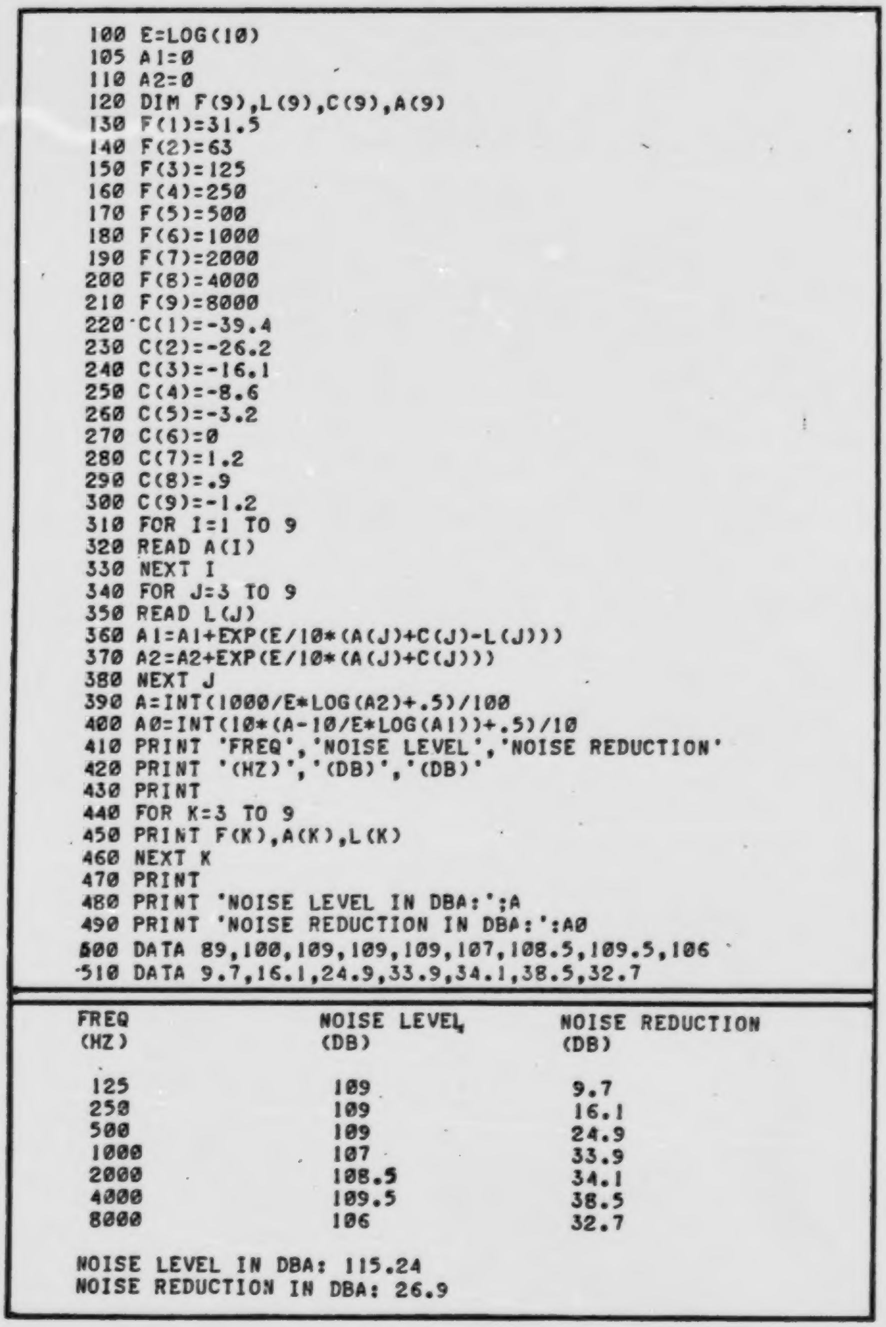
(5) *Operation:* The earmuff to be measured is positioned so that the points of attachment of the headband to the earcups are located at the centerline marks (13.08 cm) and the headband contacts the vertical post. The post is moved away, and the weight is positioned to where the pointers are aligned. The force is read from the scale which converts weight location into grams. When the pointers are aligned, the distance of 14.35 cm is automatically satisfied.

(6) *Accuracy:* The positioning of the earcup must be done with care in order to ensure that the point of attachment of the cup to the headband is the distance *a* from the pivot point. Practically, this is the largest source of error. With care, the position will be in error less than 0.3 cm for a maximum measurement error of 0.3 cm ÷ 12 cm = 2.6% (2.1 % for a = 15 cm). Actual measurements of ten different hearing protectors by three different persons have shown that 95% of the measurements will be within ±50g (about 2 ounces).

APPENDIX B

Programs

Computer Program for Calculating the Effective Noise Reduction (Attenuation) of Ear Muffs



```
100 E=LOG(10)
105 A1=0
110 A2=0
120 DIM F(9),L(9),C(9),A(9)
130 F(1)=31.5
140 F(2)=63
150 F(3)=125
160 F(4)=250
170 F(5)=500
180 F(6)=1000
190 F(7)=2000
200 F(8)=4000
210 F(9)=8000
220 C(1)=-39.4
230 C(2)=-26.2
240 C(3)=-16.1
250 C(4)=-8.6
260 C(5)=-3.2
270 C(6)=0
280 C(7)=1.2
290 C(8)=.9
300 C(9)=-1.2
310 FOR I=1 TO 9
320 READ A(I)
330 NEXT I
340 FOR J=3 TO 9
350 READ L(J)
360 A1=A1+EXP(E/10*(A(J)+C(J)-L(J)))
370 A2=A2+EXP(E/10*(A(J)+C(J)))
380 NEXT J
390 A=INT(1000/E*LOG(A2)+.5)/100
400 A0=INT(10*(A-10/E*LOG(A1))+.5)/10
410 PRINT 'FREQ','NOISE LEVEL','NOISE REDUCTION'
420 PRINT '(HZ)','(DB)','(DB)'
430 PRINT
440 FOR K=3 TO 9
450 PRINT F(K),A(K),L(K)
460 NEXT K
470 PRINT
480 PRINT 'NOISE LEVEL IN DBA:';A
490 PRINT 'NOISE REDUCTION IN DBA:';A0
500 DATA 89,100,109,109,109,107,108.5,109.5,106
510 DATA 9.7,16.1,24.9,33.9,34.1,38.5,32.7
```

```
FREQ                NOISE LEVEL         NOISE REDUCTION
(HZ)                (DB)                (DB)

 125                 109                 9.7
 250                 109                 16.1
 500                 109                 24.9
 1000                107                 33.9
 2000                108.5               34.1
 4000                109.5               38.5
 8000                106                 32.7

NOISE LEVEL IN DBA: 115.24
NOISE REDUCTION IN DBA: 26.9
```

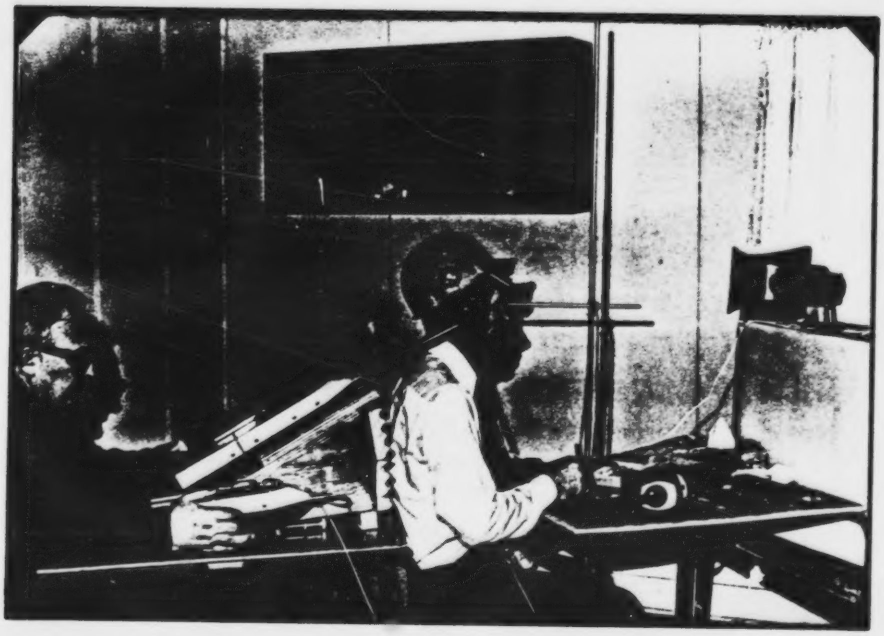
Program

Calculate A-Weighted Sound Level from Octave Band Levels Using a Hewlett-Packard HP-35

Step No.	Enter Data	Operation		Step No.	Enter Data	Operation	
		Enter	Press			Enter	Press
1	$L_{31.5}$	-	ENTER↑	20	-	10	x^y
2	-	39.4	—	21	L_{1k}	-	ENTER↑
3	-	10	÷	22	-	10	÷
4	-	10	x^y	23	-	10	x^y
5	L_{63}	-	ENTER↑	24	L_{2k}	-	ENTER↑
6	-	26.2	—	25	-	1.2	+
7	-	10	÷	26	-	10	÷
8	-	10	x^y	27	-	10	x^y
9	L_{125}	-	ENTER↑	28	L_{4k}	-	ENTER↑
10	-	16.1	—	29	-	0.9	+
11	-	10	÷	30	-	10	÷
12	-	10	x^y	31	-	10	x^y
13	L_{250}	-	ENTER↑	32	L_{8k}	-	ENTER↑
14	-	8.6	—	33	-	1.2	—
15	-	10	÷	34	-	10	÷
16	-	10	x^y	35	-	10	x^y, +
17	L_{500}	-	ENTER↑	36	-	-	LOG
18	-	3.2	—	37	-	10	×
19	-	10	÷				

Note:

Step No. 1, for data beginning at 31.5 Hz octave band.
Step No. 5, for data beginning at 63 Hz octave band.
Step No. 9, for data beginning at 125 Hz octave band.



Psychophysical test in laboratory

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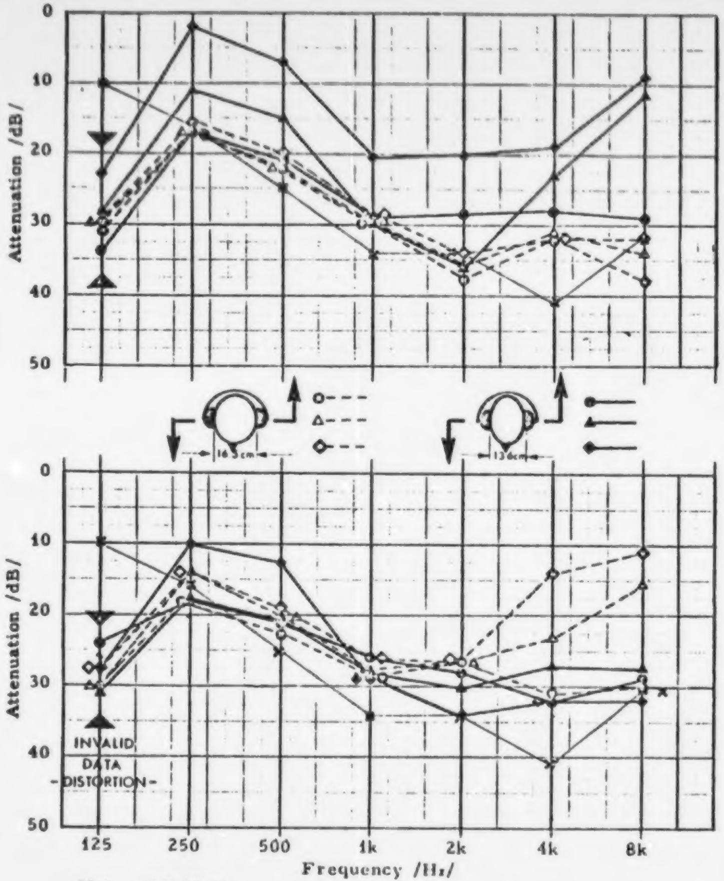
APPENDIX C

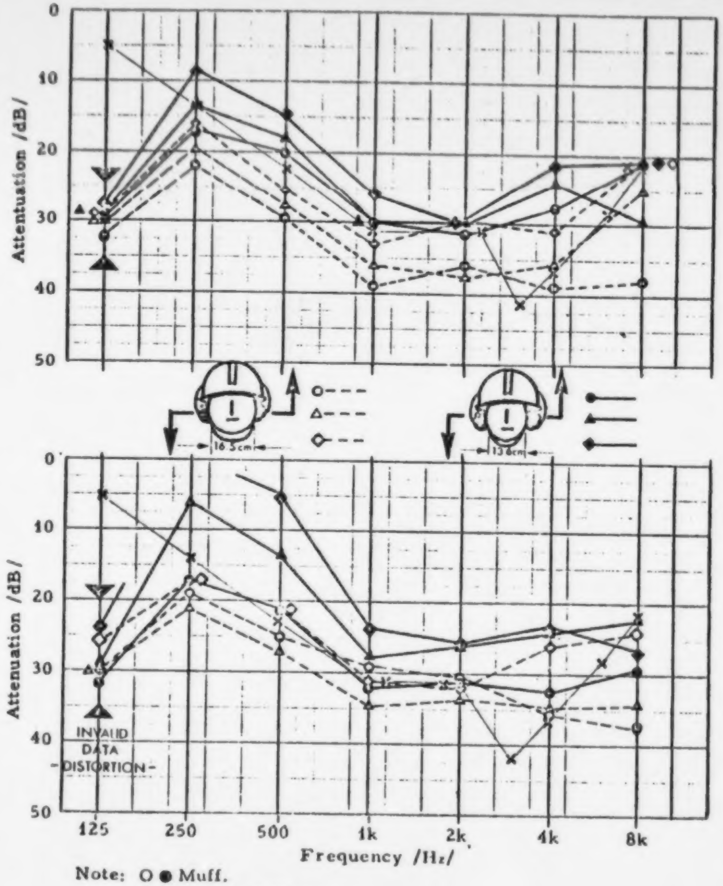
Psychophysical Test

No. 1 Ear Muff, model A



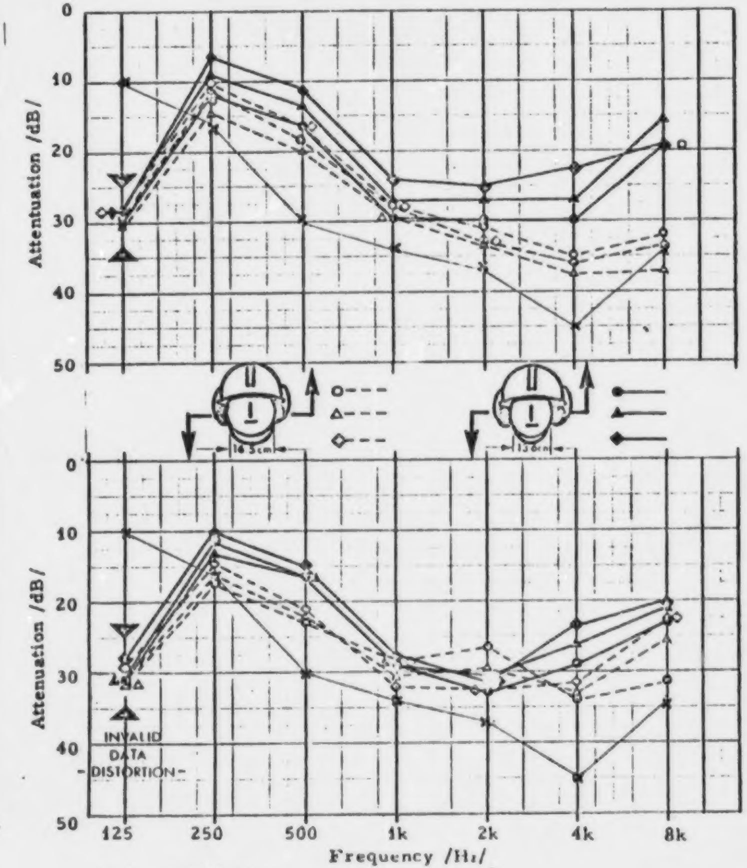
Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
× Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 2 Ear Muff, model B



Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
× Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 3 Ear Muff, model C



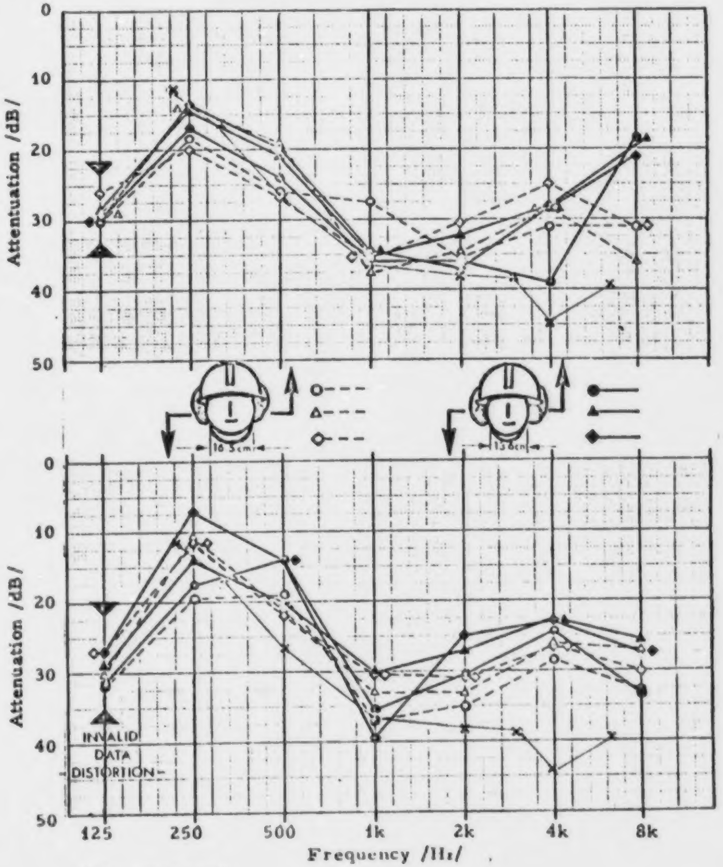
Note: ○ ● Muff.

△ ▲ Muff and Glasses.

◇ ◆ Muff, Glasses and Adapter.

x Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 4 Ear Muff, model D



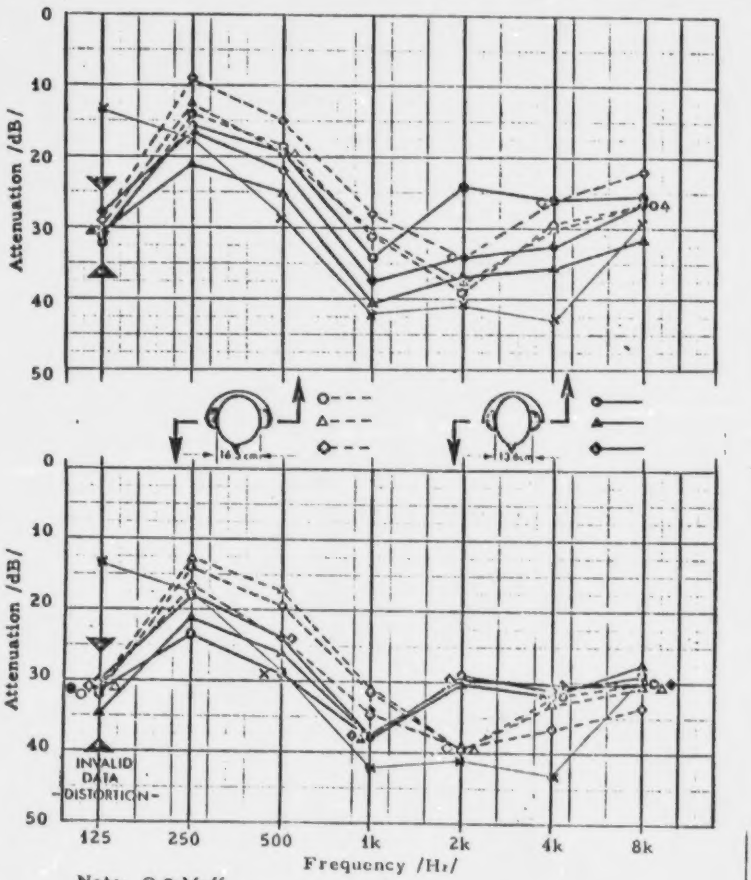
Note: ○ ● Muff.

△ ▲ Muff and Glasses.

◇ ◆ Muff, Glasses and Adapter.

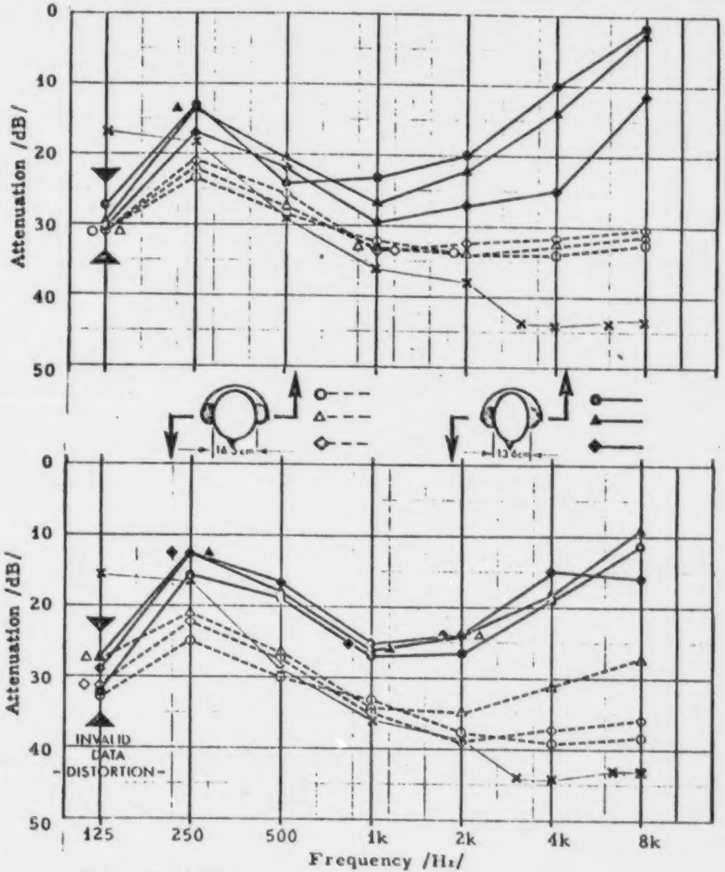
x Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 5 Ear Muff, model E



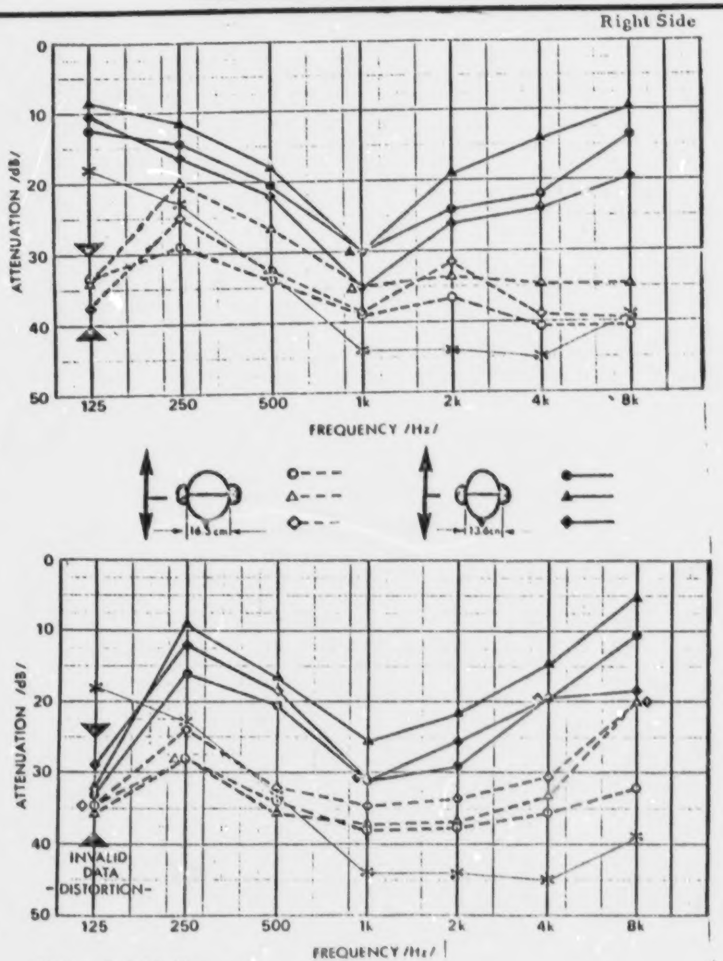
Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
× Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 6 Ear Muff, model F



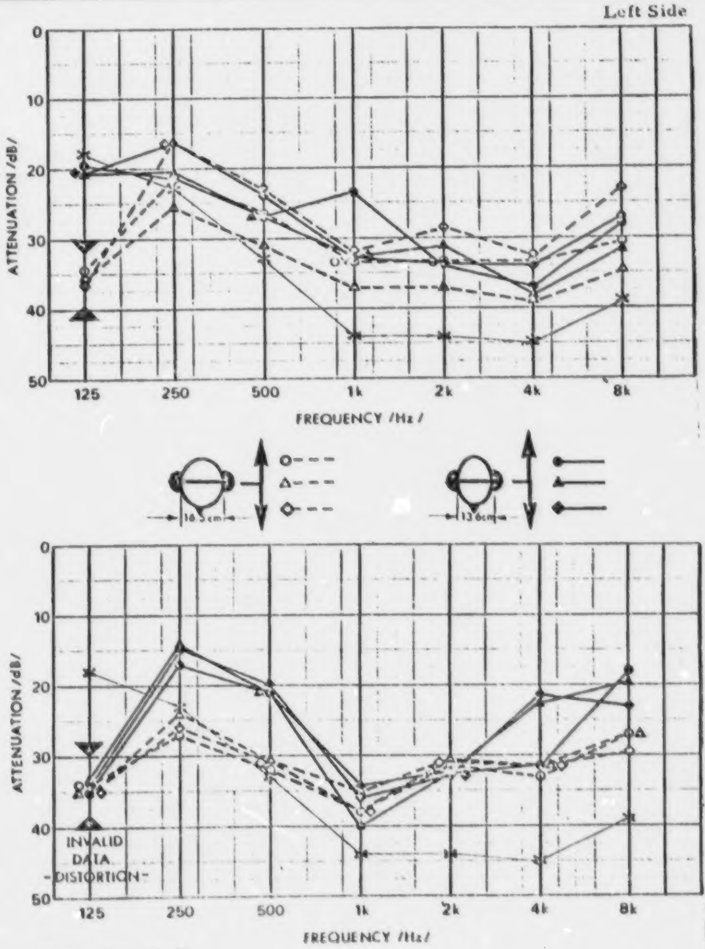
Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
× Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 7 Ear Muff, model G



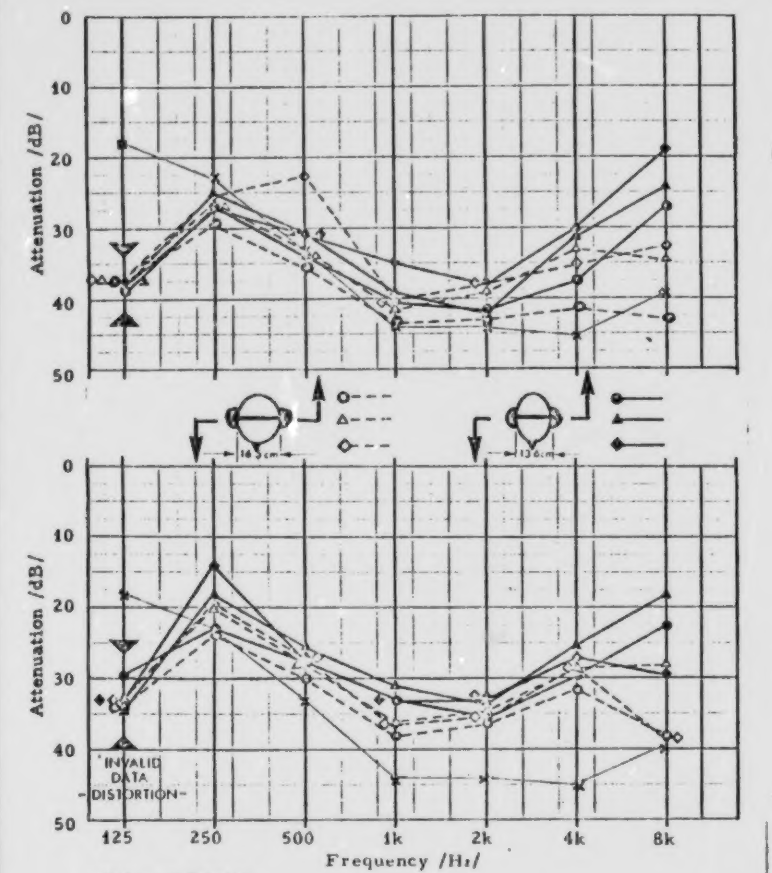
Note; ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter
✻ Attenuation characteristic measured in accordance with American National Standard Specification Z24, 22-1957.

No. 7 Ear Muff, model G



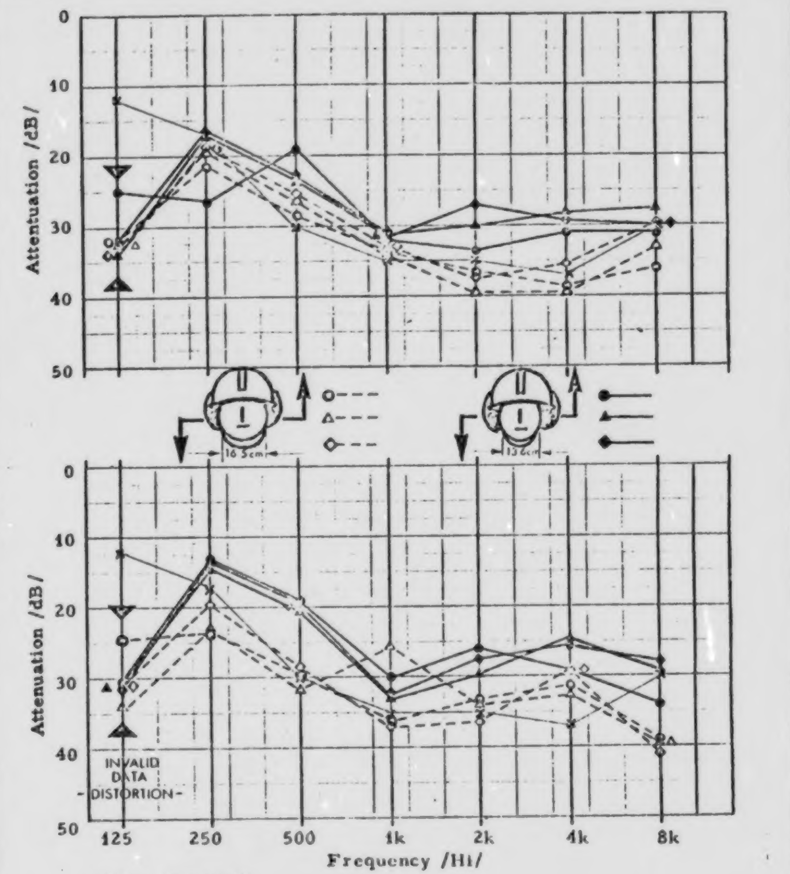
Note; ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
✻ Attenuation characteristic measured in accordance with American National Standard Specification Z24, 22-1957.

No. 8 Ear Muff, model H



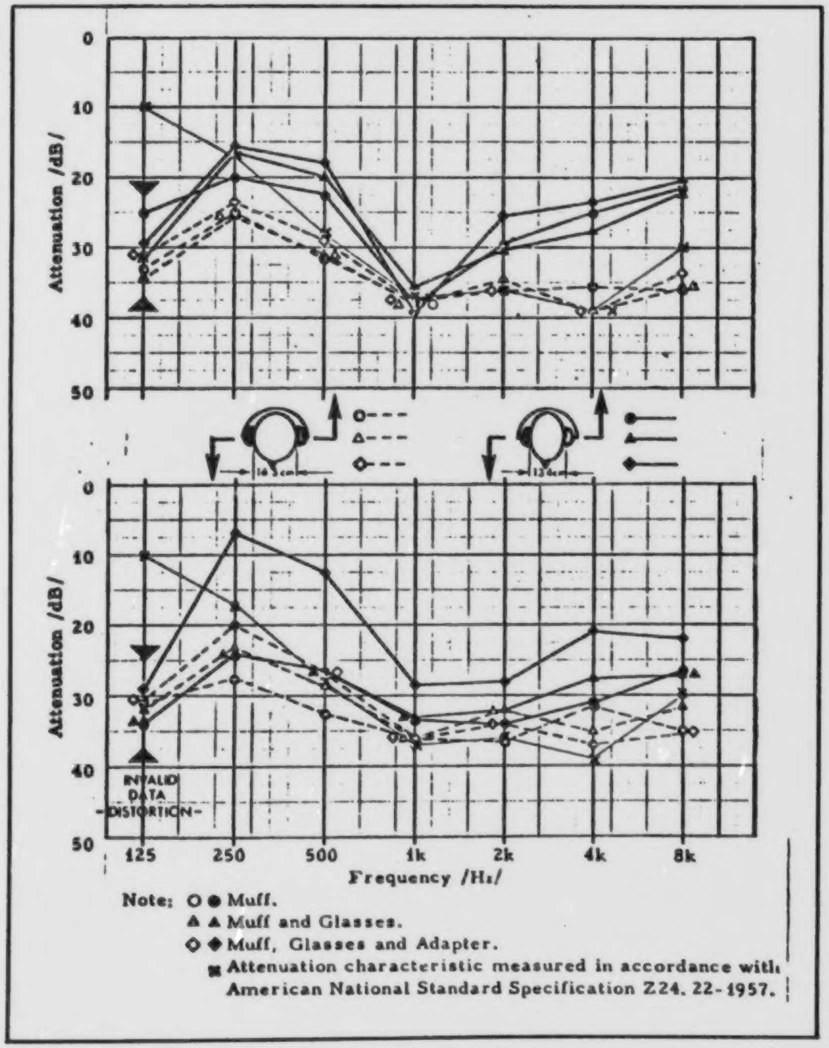
Note; ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 9 Ear Muff, Model I



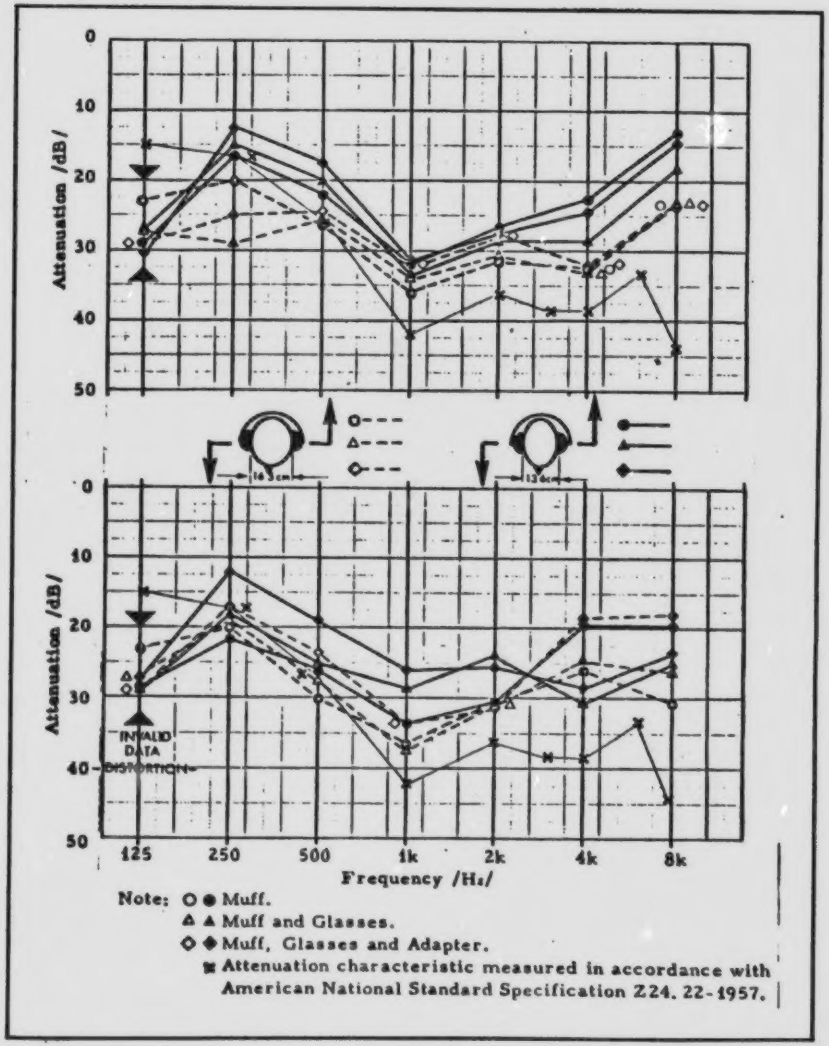
Note; ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 10 Ear Muff, model J



Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

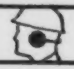
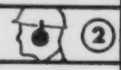
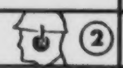
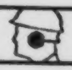
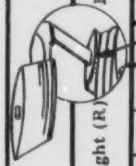
No. 11 Ear Muff, model K



Note: ○ ● Muff.
△ ▲ Muff and Glasses.
◇ ◆ Muff, Glasses and Adapter.
✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

Attenuation Reduction Data When the Neck is in Normal Position

(Subject used glasses and adapter)

	Hemisphere	No.	1		2		3		4		5		6	
		Ear Muffs	A 		B		C 		D 		E		F 	
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)	
			Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd
13.6 	Left (L)	Muff	28.5	27.5	30.5	29	37	35	31.5	31.5	24.5	25.5	17	14
		Muff and Glasses	23.5	25	26.5	27.5	33	33	30.5	29.5	36	36	14	14.5
		Muff, Glasses and Adapter	18.5	18.5	24	25	32	30	32.5	33.5	31.5	33	26	25
		Σ/3	23.5	23.7	27	27.2	34	32.7	31.5	31.5	30.7	31.5.	19	17.8
	Right (R)	Muff	29	28	32	31	32	30	28.5	29	31	30	21.5	21
		Muff and Glasses	28	28	25.5	25	28	28	26	25.5	30	31	20.5	20.5
		Muff, Glasses and Adapter	26	26	21	21	26	26.5	23.5	24.5	31	30.5	21	20
		Σ/3	27.7	27.3	26.2	25.7	28.7	28.2	26	26.3	30.7	30.5	21	20.5
	$\frac{L+R}{2}$	(Σ3 + Σ/3)/2	25.6	25.5	26.6	26.5	31.4	30.5	28.8	28.9	30.7	31	20	19.2
			Clamping Force 580 (gwt)		Clamping Force 1005 (gwt)		Clamping Force 730 (gwt)		Clamping Force 980 (gwt)		Clamping Force 1980 (gwt)		Clamping Force 1180 (gwt)	
16.5	Left (L)	Muff	34.5	34	37	37	31	30	34	33.5	32.5	32.5	35	33.5
		Muff and Glasses	33.5	33	35	35	33.5	32.5	32	31	32.5	32.5	33	33.5
		Muff, Glasses and Adapter	32.5	32	29.5	29.5	33	31	29	28.5	29.5	29	32.5	32
		Σ/3	33.5	33	33.8	33.8	32.5	31.2	31.7	31	31.5	31.3	33.5	33
	Right (R)	Muff	28.5	28	32	31	28.5	28	32.5	33	34	33.5	26.5	36.5
		Muff and Glasses	29	24.5	34	34	30	30	30.5	30	34	33.5	33.5	33.5
		Muff, Glasses and Adapter	19.5	19	30	30	30.5	31.5	29.5	29.5	31	32.5	37.5	37
		Σ/3	25.7	23.8	32	31.7	29.7	29.8	30.8	30.8	33	33.2	35.8	35.7
	$\frac{L+R}{2}$	(Σ/3 + Σ/3)/2	29.6	28.4	32.9	32.8	31.1	30.5	31.3	30.9	32.3	32.3	34.7	34.4
			Clamping Force 780 (gwt)		Clamping Force 1355 (gwt)		Clamping Force 930 (gwt)		Clamping Force 1230 (gwt)		Clamping Force 2580 (gwt)		Clamping Force 1580 (gwt)	

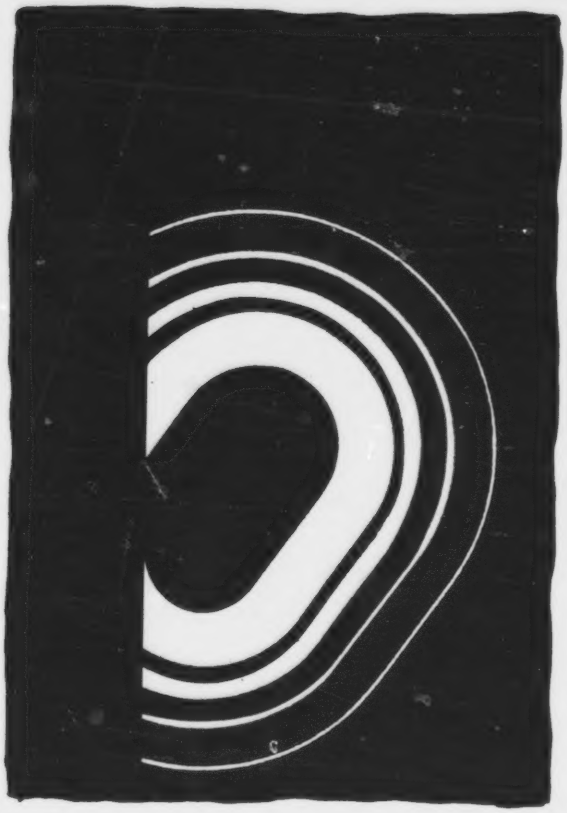
Est'd: Total noise estimated from the octave-band levels given in Appendix B-2. Approximate agreement with measured total noise indicates reasonably constant conditions during period of measurement.

	Hemisphere	No.	7++		8		9		10		11		Arithmetic Mean of all Ear Muffs			
		Ear Muffs	G		H		I ②		J		K					
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Mean Attenuation (dBA)			
			Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	St. dev.	Est'd	St. dev.
13.6	Left (L)	Muff	-	30.7	32.5	35.5	31.5	31	29.5	31	23	24	28.55	5.67	28.4	6.27
		Muff and Glasses	-	30.4	30	28.5	29.5	29	29	29	28	28	28	5.97	28	5.63
		Muff, Glasses and Adapter	-	30.5	31.5	31	28.5	28	31	26	24.5	24.5	28	4.62	27.45	4.59
		Σ/3	-	30.5	31.3	31.7	29.8	29.3	29.8	28.7	25.2	25.5	28.18	4.51	27.96	4.62
	Right (R)	Muff	-	23.5	42	42.5	27	27	33	32	25	29.5	30.1	5.49	30	5.34
		Muff and Glasses	-	17.4	36.5	35.5	28.5	28	31.5	30	25.5	28.5	28	4.02	28	3.96
		Muff, Glasses and Adapter	-	24.8	37.5	37	27	27	29	25	26.5	23.5	26.85	4.9	26.1	4.86
		Σ/3	-	21.9	38.7	38.3	27.5	27.3	31.2	29	25.7	27.2	28.34	4.63	28.03	4.46
	$\frac{L+R}{2}$	(Σ3 + Σ/3)/2	-	26.2	35	35	28.7	28.3	30.5	28.9	25.5	26.4	28.26	3.03	28	3.01
			Clamping Force 1230 (gwt)		Clamping Force 1130 (gwt)		Clamping Force 730 (gwt)		Clamping Force 1330 (gwt)		Clamping Force 980 (gwt)					
16.5	Left (L)	Muff	-	32.6	38.5	38.5	36	35	33	36	31.5	25	34.3	2.41	33.5	3.82
		Muff and Glasses	-	34.1	34.5	35	37.5	38	31.5	36	31	25.5	33.4	1.91	33.2	3.27
		Muff, Glasses and Adapter	-	30.3	32.5	32.5	35.5	35	30	36	29.5	26	31.35	2.15	31.15	3.03
		Σ/3	-	32.3	35.2	35.3	36.3	36	31.5	36	30.7	25.5	33.02	1.78	32.61	3.14
	Right (R)	Muff	-	37.3	35	35	33	33	34	35.5	31	32	32.5	2.61	32.55	2.9
		Muff and Glasses	-	34.4	33	32.5	33.5	34	36	33	29	31	32.25	2.43	31.6	2.93
		Muff, Glasses and Adapter	-	32.7	34	33.5	34	33	36	34.5	23.5	29.5	30.55	5.53	31	4.83
		Σ/3	-	34.8	34	33.7	33.5	33.3	35.3	34.3	27.8	30.8	31.76	3.27	31.77	3.32
	$\frac{L+R}{2}$	(Σ/3 + Σ/3)/2	-	33.6	34.6	34.5	34.9	34.7	33.4	35.2	29.3	28.2	32.39	2.25	32.16	2.54
			Clamping Force 1480 (gwt)		Clamping Force 1330 (gwt)		Clamping Force 1005 (gwt)		Clamping Force 1930 (gwt)		Clamping Force 1280 (gwt)					

NOTE: ++ Measurements are not included in Arithmetic Mean of all Ear Muffs.

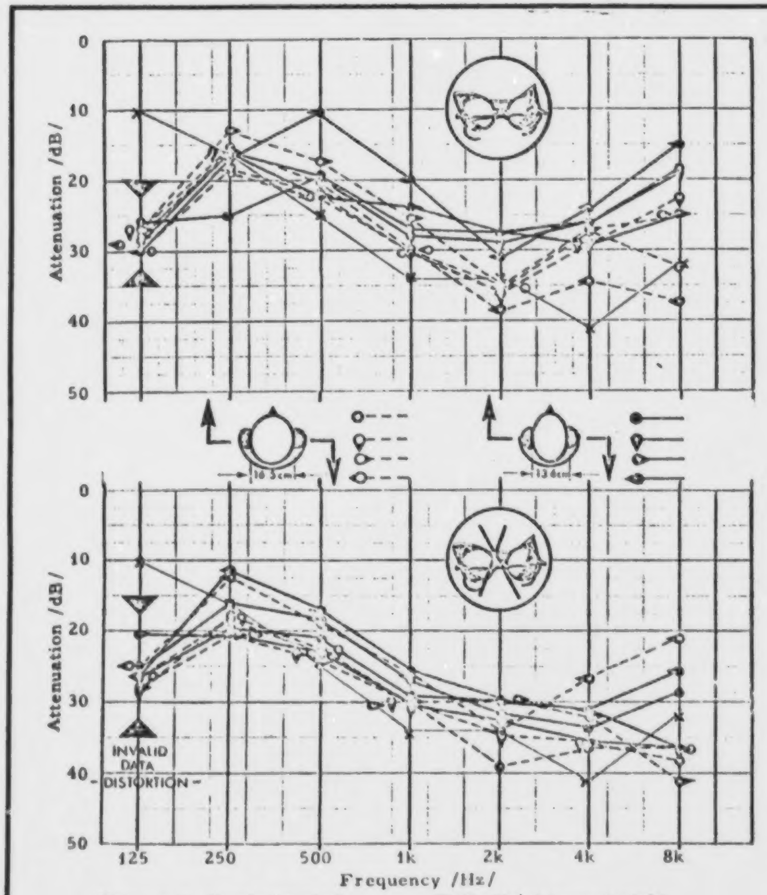
① Tested while mounted on helmet; B x 18A Safety Cap, CSA Standard Z 94.1.

② Tested while mounted on helmet; Class C, CSA Standard Z 94.1.



Vignette

No. 1 Ear Muff, model A

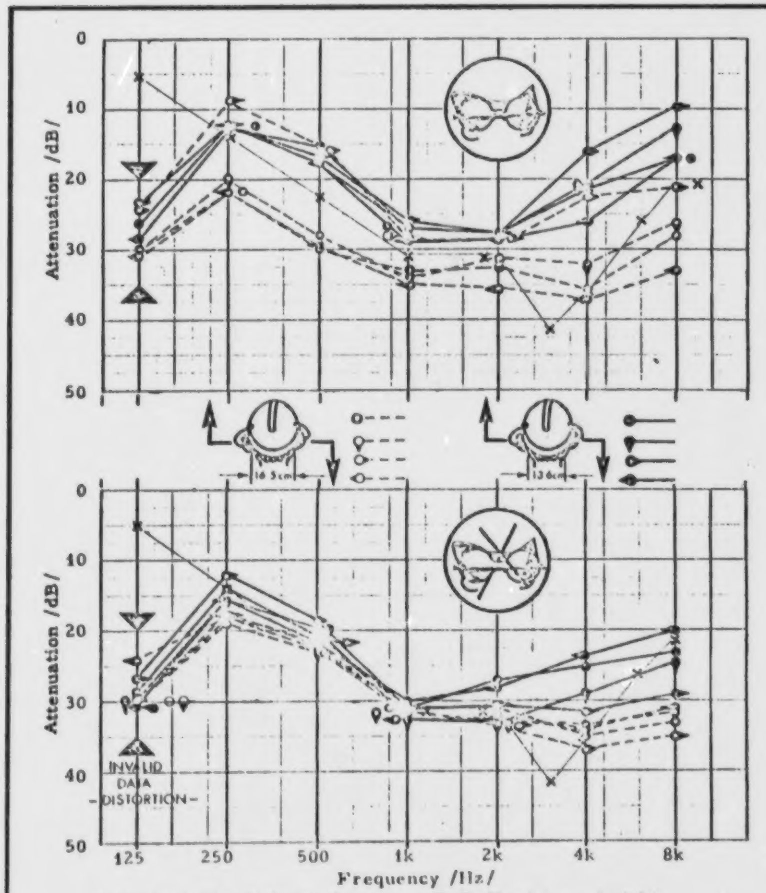


Note: ○ ● Head elevated ◔ ● Head turned right

⚲ ⚲ Head lowered ◔ ● Head turned left

× Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 2 Ear Muff, model B

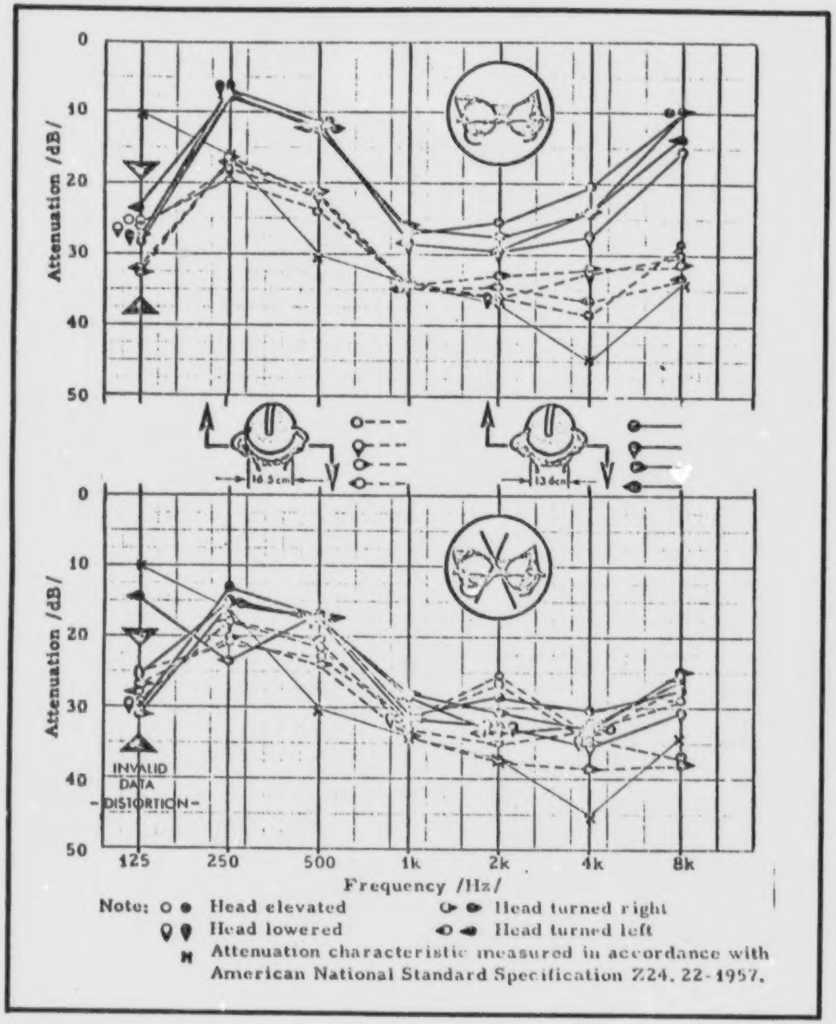


Note: ○ ● Head elevated ◔ ● Head turned right

⚲ ⚲ Head lowered ◔ ● Head turned left

× Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 3 Ear Muff, model C

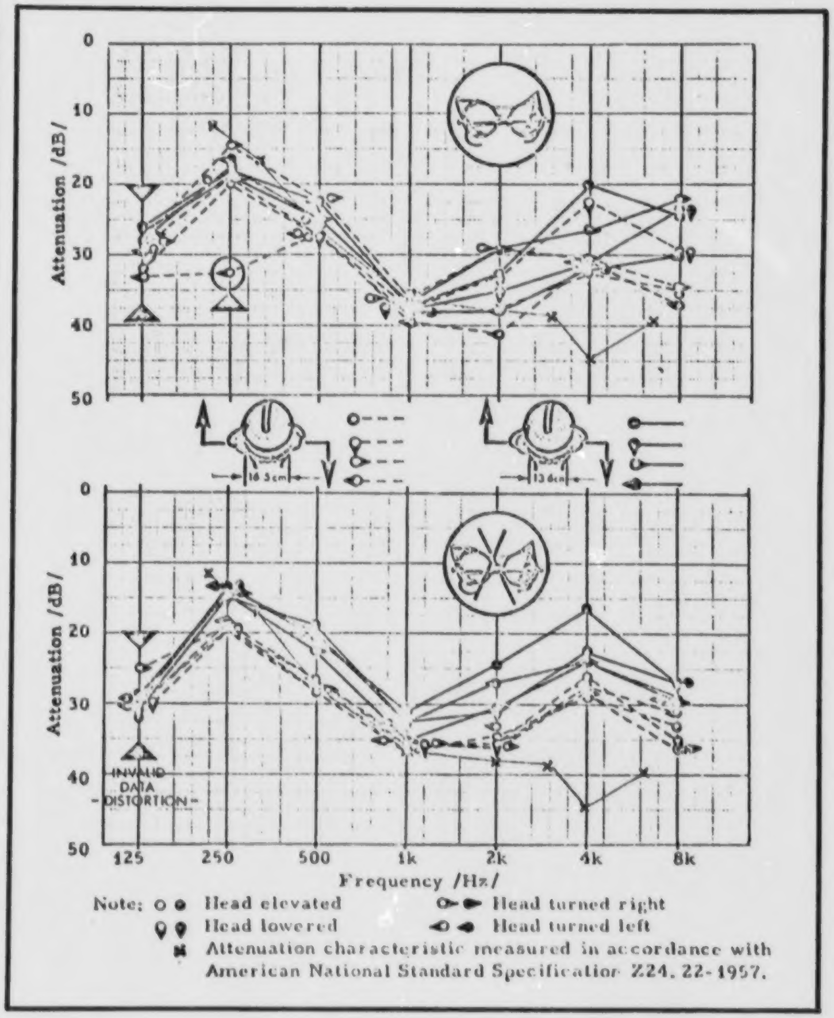


Note: ○ ● Head elevated ◔ ● Head turned right

⚲ ⚲ Head lowered ◔ ◀ Head turned left

× Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 4 Ear Muff, model D

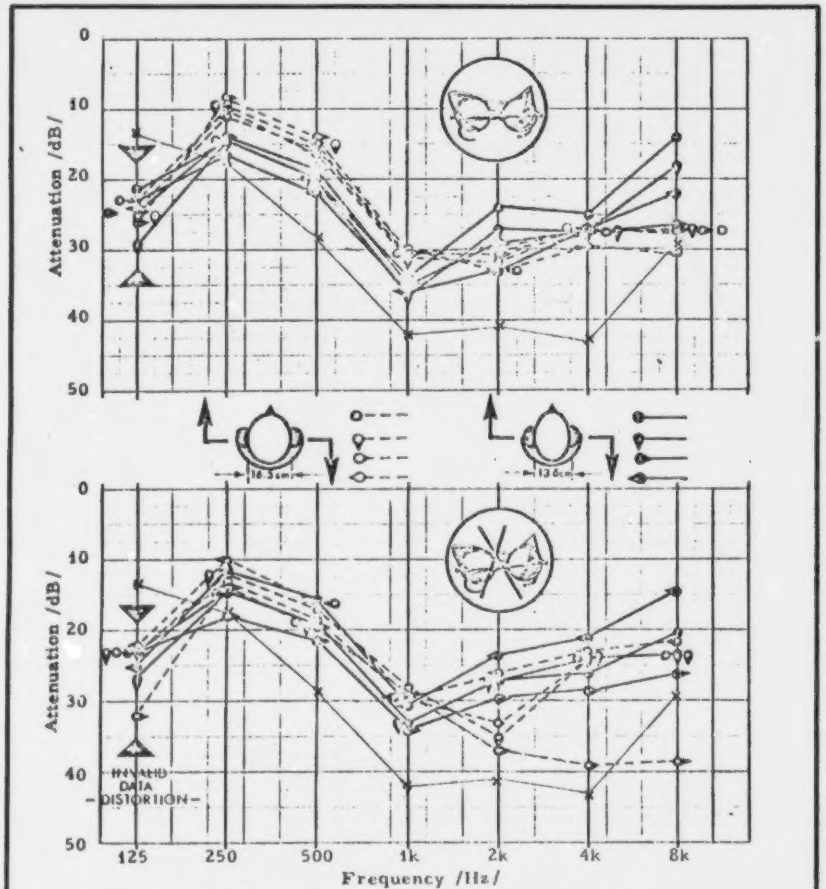


Note: ○ ● Head elevated ◔ ● Head turned right

⚲ ⚲ Head lowered ◔ ◀ Head turned left

× Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 5 Ear Muff, model E

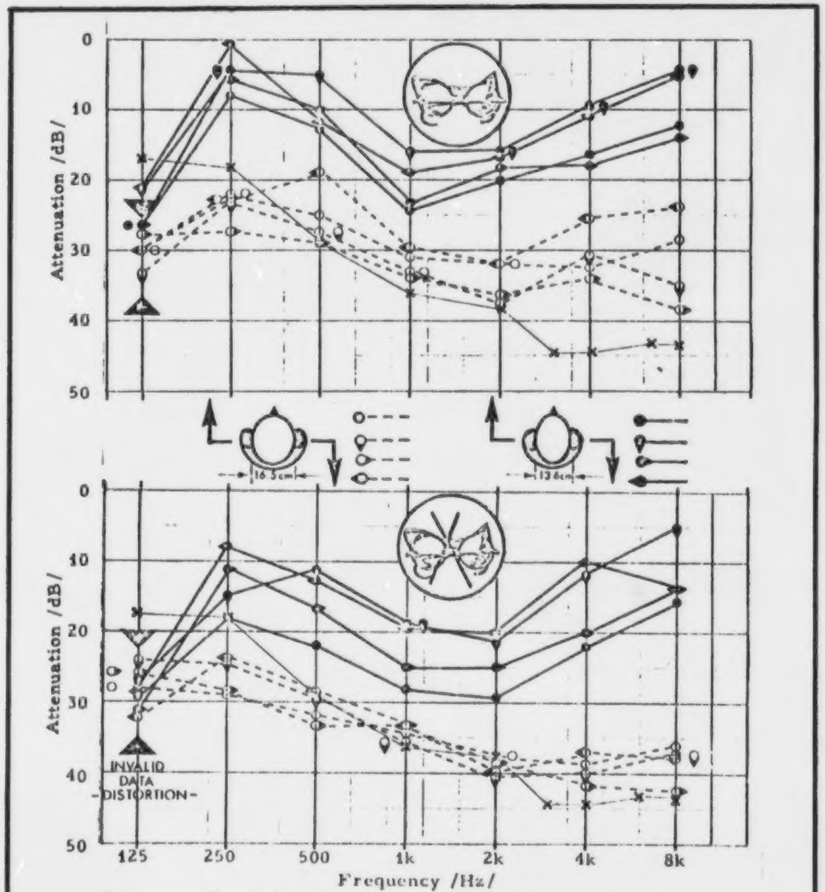


Note: ○ ● Head elevated ⊙ ● Head turned right

♀ ♥ Head lowered ⊙ ● Head turned left

✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 6 Ear Muff, model F

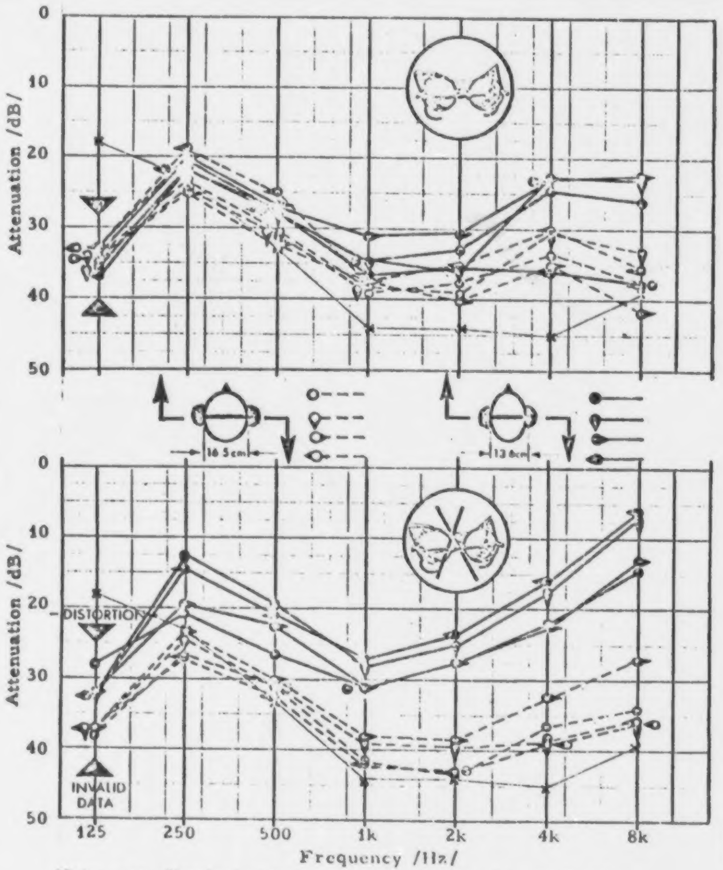


Note: ○ ● Head elevated ⊙ ● Head turned right

♀ ♥ Head lowered ⊙ ● Head turned left

✖ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 8 Ear Muff, model H

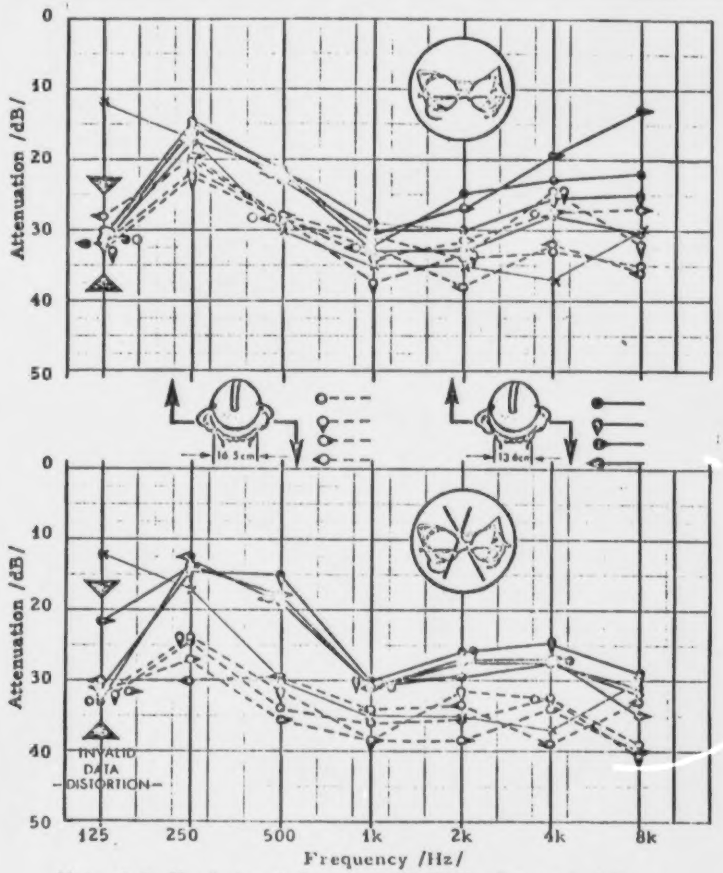


Note: ○ ● Head elevated ◐ ● Head turned right

♀ ♀ Head lowered ◐ ● Head turned left

■ Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 9 Ear Muff, model I

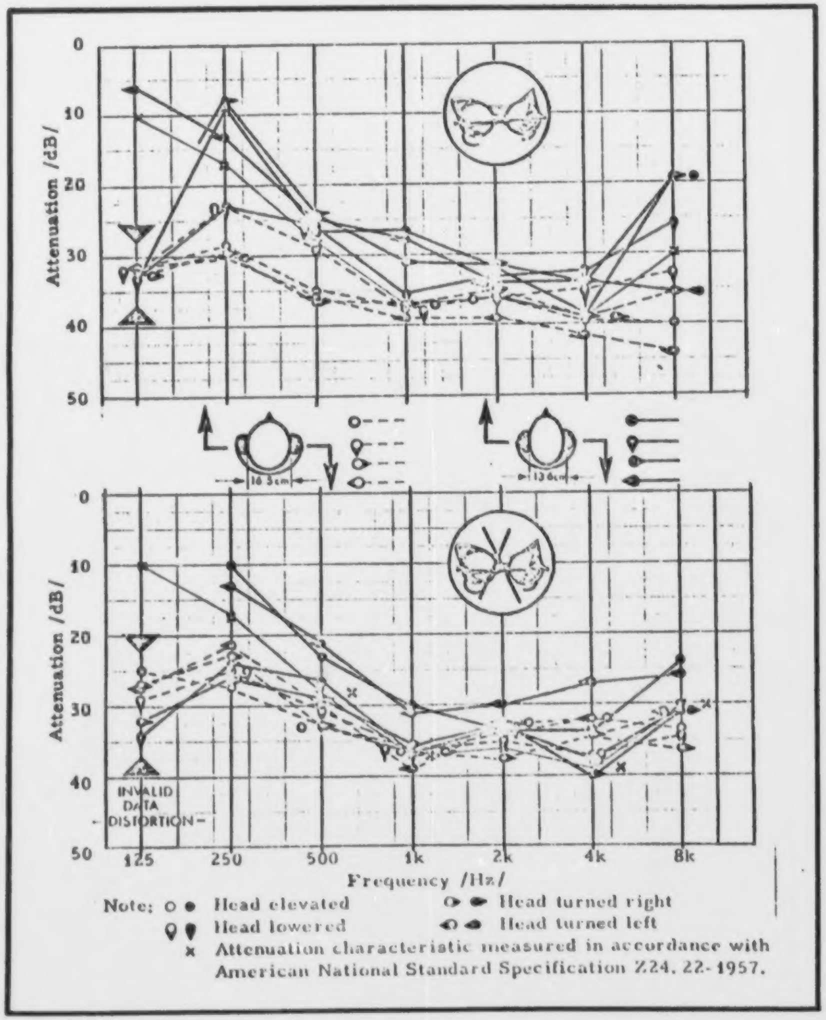


Note: ○ ● Head elevated ◐ ● Head turned right

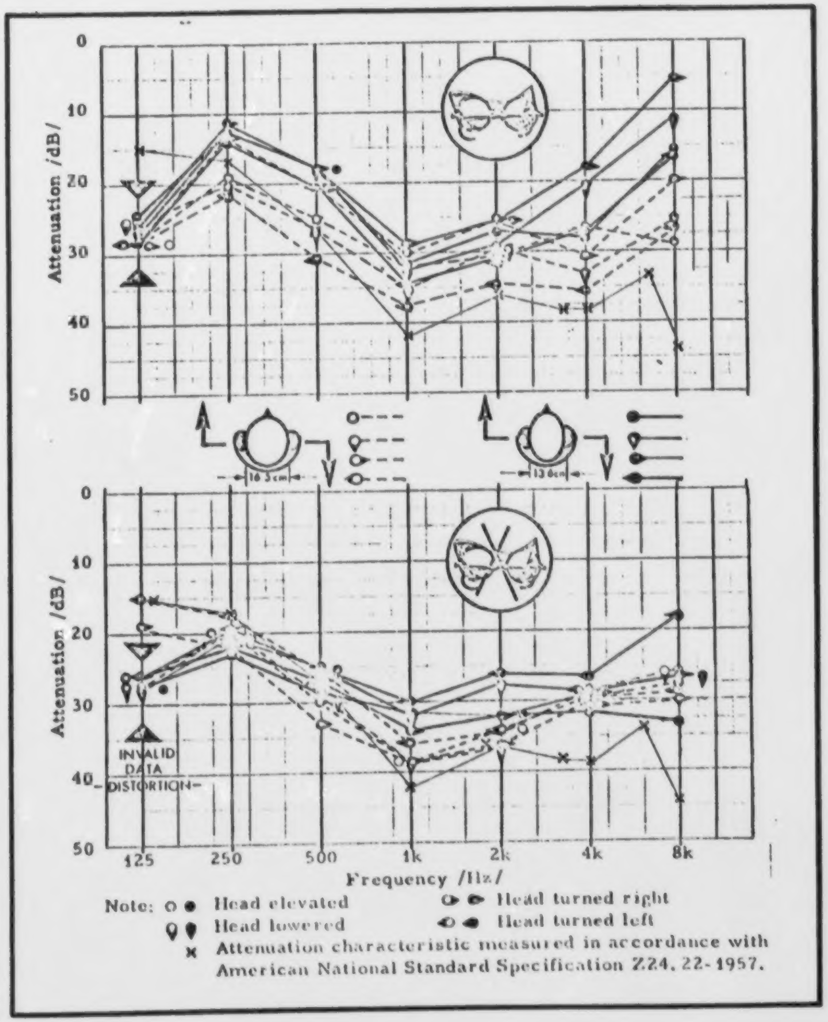
♀ ♀ Head lowered ◐ ● Head turned left

× Attenuation characteristic measured in accordance with American National Standard Specification Z24. 22-1957.

No. 10 Ear Muff, model J

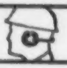
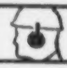
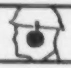
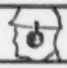
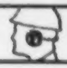
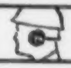


No. 11 Ear Muff, model K

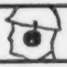


Attenuation Reduction Data When the Neck Joint is Flexed and When the Neck is Rotated

(Subject 1 [D = 13.6 cm] and subject 2 [D = 16.5 cm] used glasses)

	Hemisphere	No.	1		2		3		4		5		6	
		Ear Muffs	A 		B  ①		C  ②		D  ②		E 		F 	
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)	
			Meas.	Est'd	Meas.	Est'd	Meas.	Est'd	Meas.	Est't	Meas.	Est'd	Meas.	Est'd
13.6	Left (L)	Head elevated	27	26	24.5	25	22	22	31	25.5	22	23.5	19.5	20
		Head lowered	27	27	23	23.5	25.5	26	32.5	33	25.5	26.5	14	14.5
		Head turned right	27.5	27	21	21	20	23	28.5	29.5	27	27.5	13.5	13.5
		Head turned left	26.5	22	26	27	25.5	24.5	35.5	35.5	32	29	20.5	18.5
		Σ/4	27	25.5	23.6	24.1	23.25	23.9	31.9	30.9	26.6	26.6	16.9	16.6
	Right (R)	Head elevated	31	30	27	27	29	28.5	27	20	33.5	27	26	26
		Head lowered	29	29.5	30.5	34	32.5	32	27	27.5	33.5	26	17	16
		Head turned right	32.5	32.5	30	28.5	30	29.5	29	28.5	29	29.5	22.5	22.5
		Head turned left	28	26.5	25	25.5	30.5	30	24	26.5	22.5	23	15	15.5
		Σ/4	30.1	29.6	28.1	28.75	30.5	30	26.75	25.6	29.6	26.4	20.1	20
	$\frac{L+R}{2}$	(Σ/4 + Σ/4)/2	28.55	27.55	25.85	26.43	26.88	26.95	29.33	28.25	28.1	26.5	18.45	18.3
			Clamping Force 580 (gwt)		Clamping Force 1005 (gwt)		Clamping Force 730 (gwt)		Clamping Force 980 (gwt)		Clamping Force 1980 (gwt)		Clamping Force 1180 (gwt)	
16.5	Left (L)	Head elevated	32.5	32	33	32.3	30.5	35	34.5	34.5	28	28	32.5	31.5
		Head lowered	31.5	31	31.5	31.4	31	34	28	32	28	28	34.5	34.5
		Head turned right	29	28.5	25	25	25	32	31	30	27.5	26.5	30	28.5
		Head turned left	35	34.5	35.5	35.5	34	34	35.5	36.5	31	29.5	35.5	35
		Σ/4	32	31.5	31.25	31.05	30.13	33.75	32.25	33.25	28.6	28	33.1	32.4
	Right (R)	Head elevated	32.5	31	31	32	26.5	33.5	33	32	28.5	29	37	37
		Head lowered	31.5	32.5	33	33	35	34.5	32	32	27.5	28.5	39.5	40
		Head turned right	35.5	35	34	33	36	36	35.5	33	30.5	32	38.5	38
		Head turned left	28.5	30	32	32	33.5	33.5	31.5	31.5	23.5	25	38	37
		Σ/4	32	32.1	32.5	32.5	32.75	34.4	33	32.1	27.5	28.6	38.25	38
	$\frac{L+R}{2}$	(Σ/4 + Σ/4)/2	32	31.8	31.88	31.78	31.44	34.07	32.63	32.68	28.05	28.3	35.68	35.2
			Clamping Force 780 (gwt)		Clamping Force 1355 (gwt)		Clamping Force 930 (gwt)		Clamping Force 1230 (gwt)		Clamping Force 2580 (gwt)		Clamping Force 1580 (gwt)	

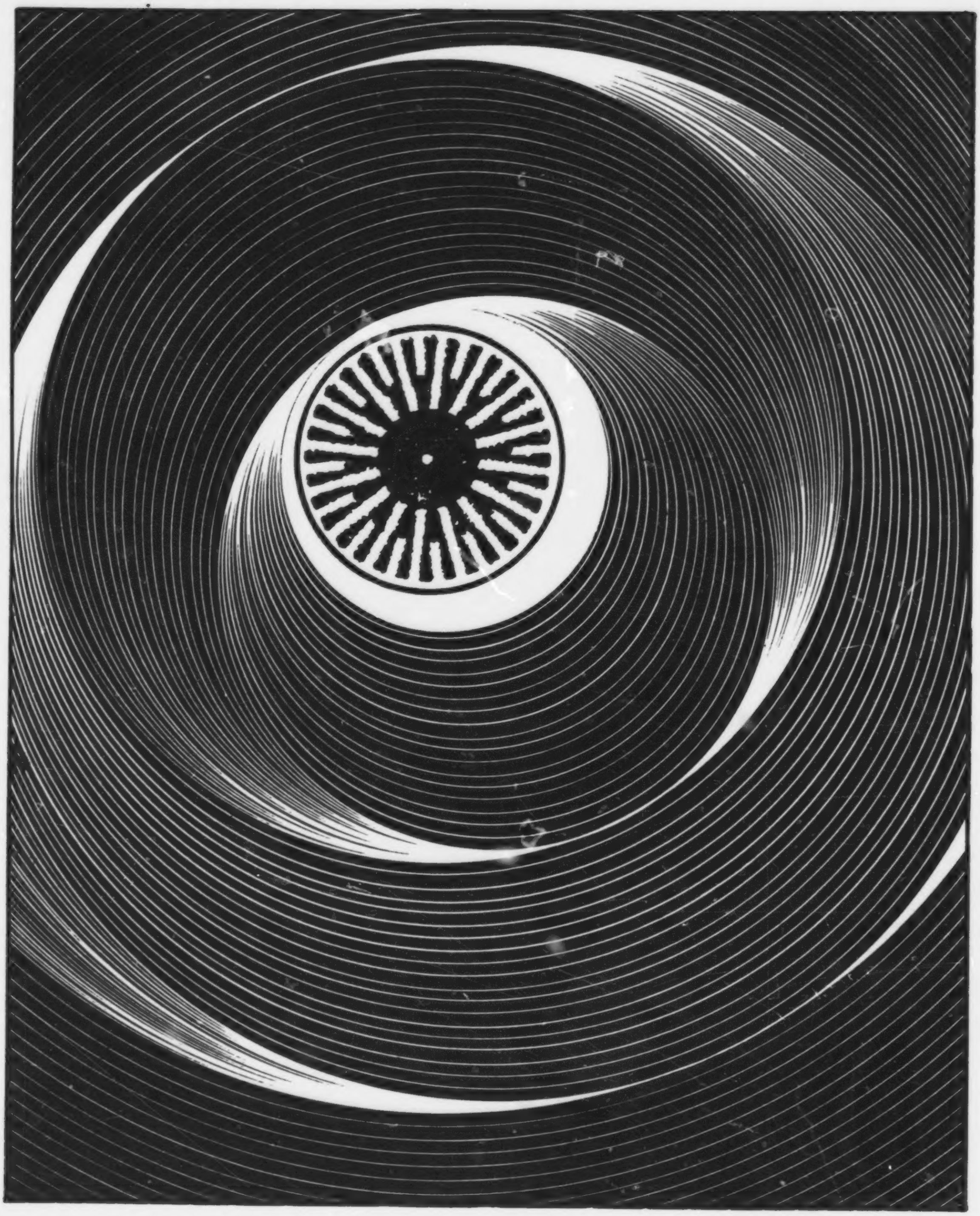
Est'd: Total noise estimated from the octave-band levels given in Appendix B-2. Approximate agreement with measured total noise indicates reasonably constant conditions during period of measurement.

	Hemisphere	No.	7		8		9		10		11		Arithmetic Mean of all Ear Muffs			
		Ear Muffs	G		H		I  ②		J		K					
		Measurements Using Human Heads	Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Attenuation (dBA)		Mean Attenuation (dBA)			
			Meas.	Est'd	Meas.	Est'd	Meas.	Est't	Meas.	Est'd	Meas.	Est'd	Meas.	St. dev.	Est'd	St. dev.
13.6	Left (L)	Head elevated	-	-	29	28.5	24.5	25	30.5	34	26	26.5	25.6	3.84	25.6	3.79
		Head lowered	-	-	28	28.5	27.5	27.5	31.5	35.5	23.5	24	25.8	5.15	26.6	5.66
		Head turned right	-	-	27.5	28	23	23.5	33.5	36.5	20	20	24.15	5.74	24.95	6.25
		Head turned left	-	-	30	30	30.5	31	33	33	28.5	28	28.8	4.35	27.85	5.10
		$\Sigma/4$	-	-	28.6	28.75	26.4	26.75	32.1	34.75	24.5	24.6	26.1	4.45	26.25	4.80
	Right (R)	Head elevated	-	-	25	27.5	28	27.5	32.5	36.9	29	28	28.8	2.79	27.84	4.13
		Head lowered	-	-	22	21.5	26	24.5	32	35.6	27.5	27.5	27.7	5.11	27.41	5.88
		Head turned right	-	-	25	25	27	27	28.5	36.4	30.5	31	28.4	2.89	29.04	3.86
		Head turned left	-	-	20.5	19	27.5	28.5	34	39.4	26	26	25.3	5.31	25.99	6.42
		$\Sigma/4$	-	-	23.1	23.25	27.1	26.9	31.75	37.1	28.25	28.1	27.54	3.56	27.57	4.52
	$\frac{L+R}{2}$	$(\Sigma/4 + \Sigma/4)/2$	-	-	25.85	26	26.75	26.83	31.93	35.93	26.38	26.35	26.82	3.81	26.91	3.05
			Clamping Force 1230 (gwt)		Clamping Force 1130 (gwt)		Clamping Force 730 (gwt)		Clamping Force 1330 (gwt)		Clamping Force 980 (gwt)					
16.5	Left (L)	Head elevated	-	-	37	36	32.5	33	31	36.5	29	28.5	32.05	2.61	32.73	2.90
		Head lowered	-	-	36	35.5	29.5	29.5	30.5	35.5	30.5	30.5	31.1	2.55	32.19	2.59
		Head turned right	-	-	39	38.5	29	29.5	30.5	36.5	27	27	29.3	4.01	30.2	4.33
		Head turned left	-	-	35.5	34	34.5	35.5	35.5	39.5	33.5	35.5	34.55	1.44	34.95	2.49
		$\Sigma/4$	-	-	36.9	36	31.4	31.9	31.9	37	30	30.4	31.75	2.23	32.52	2.64
	Right (R)	Head elevated	-	-	38.5	40.5	24.5	24.5	30.5	34	33	32	32.1	4.59	32.55	4.30
		Head lowered	-	-	38.5	39	34	32.5	33.5	35.5	33	32.5	33.75	3.43	34	3.42
		Head turned right	-	-	36	36.5	36	37	36	36.5	34.5	34	35.25	2.04	35.1	2.01
		Head turned left	-	-	42	41.5	31.5	34.5	32.5	33	35	32	32.8	5.01	33	4.32
		$\Sigma/4$	-	-	38.75	39.4	31.5	32.1	34.6	34.75	33.9	32.6	33.48	3.26	33.66	3.14
	$\frac{L+R}{2}$	$(\Sigma/4 + \Sigma/4)/2$	-	-	37.83	37.7	31.45	32	33.25	35.88	31.95	31.5	32.62	2.34	33.09	5.78
			Clamping Force 1480 (gwt)		Clamping Force 1330 (gwt)		Clamping Force 1005 (gwt)		Clamping Force 1930 (gwt)		Clamping Force 1280 (gwt)					

NOTE:

① Tested while mounted on helmet; B x 18A Safety Cap, CSA Standard Z 94.1.

② Tested while mounted on helmet; Class C, CSA Standard Z 94.1.

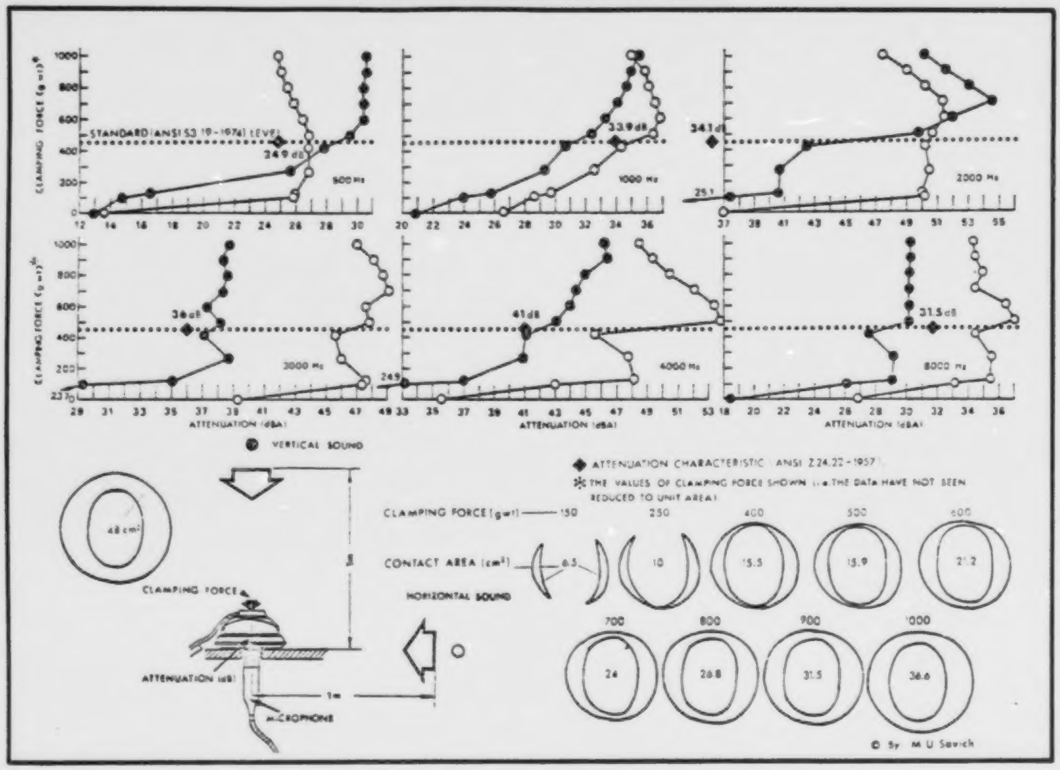


Vignette

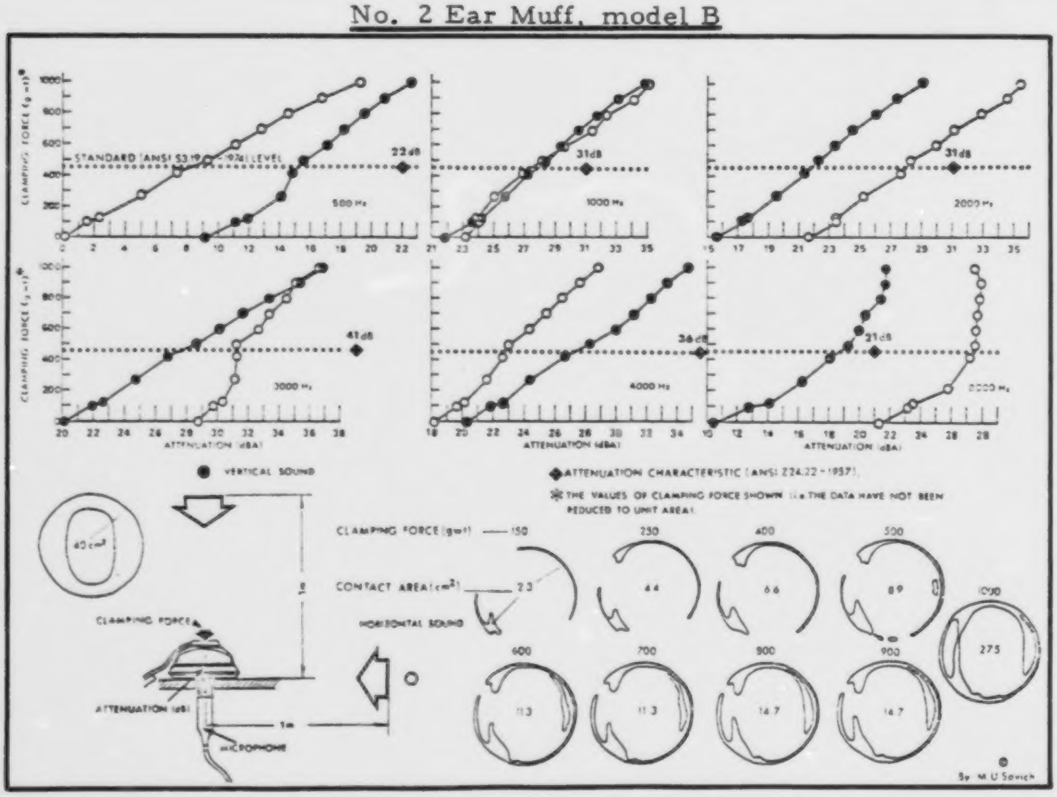
APPENDIX D

Physical Test

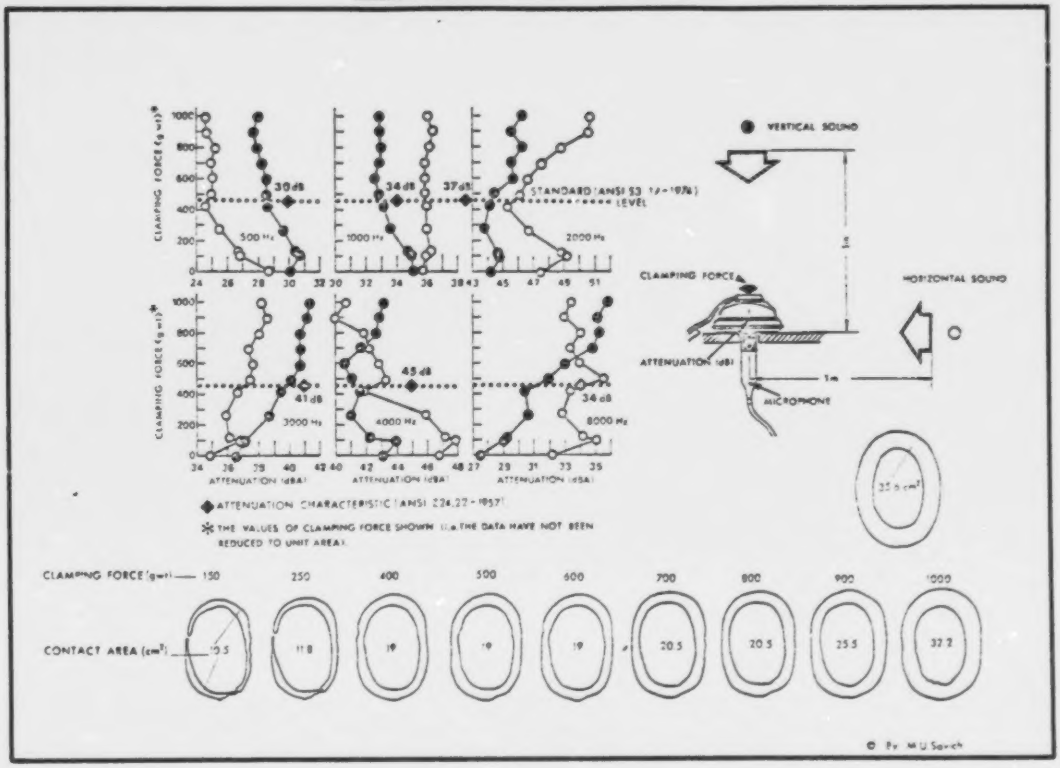
No. 1 Ear Muff, model A



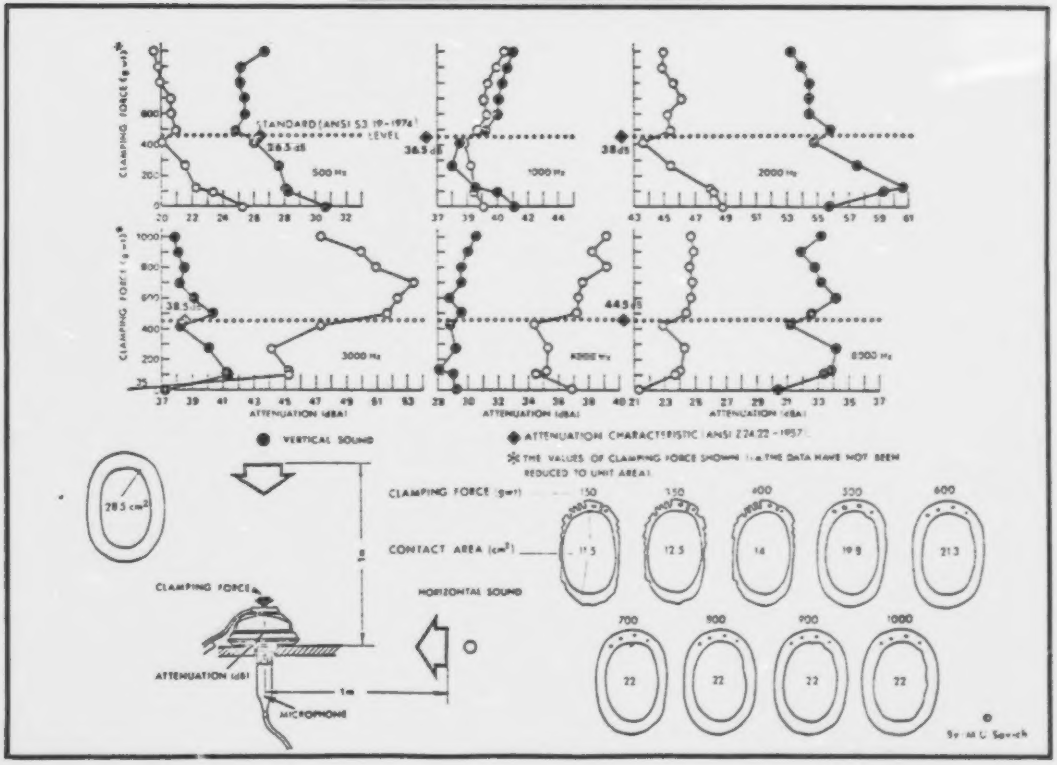
No. 2 Ear Muff, model B



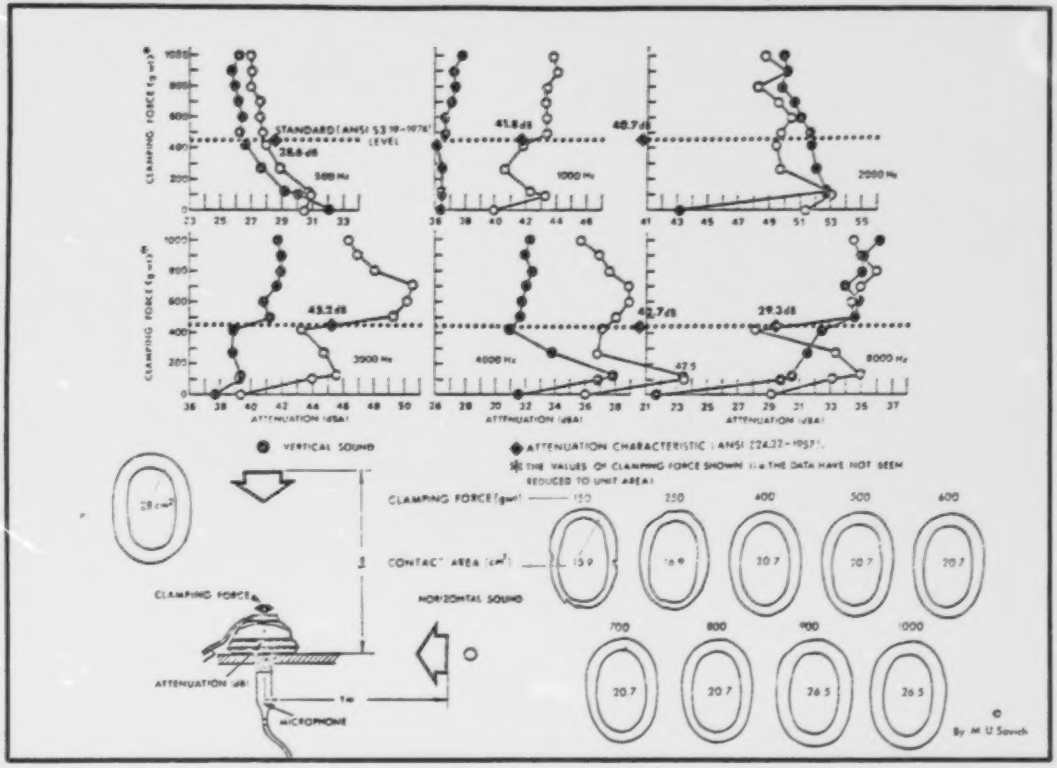
No. 3 Ear Muff, model C



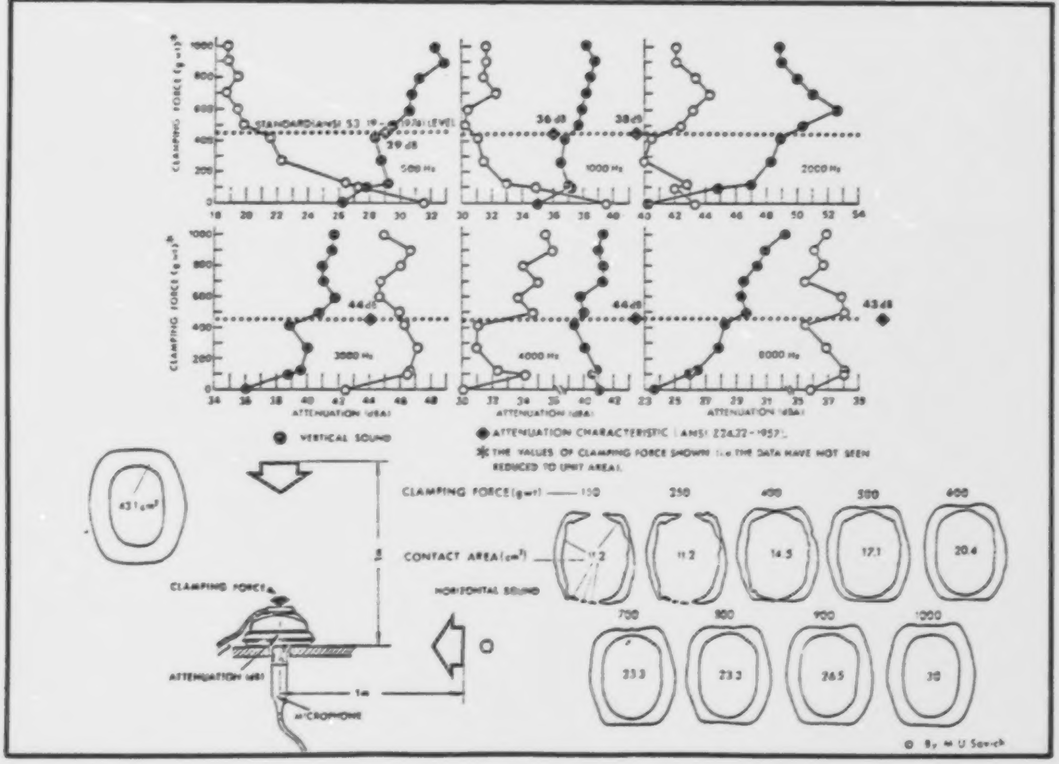
No. 4 Ear Muff, model D



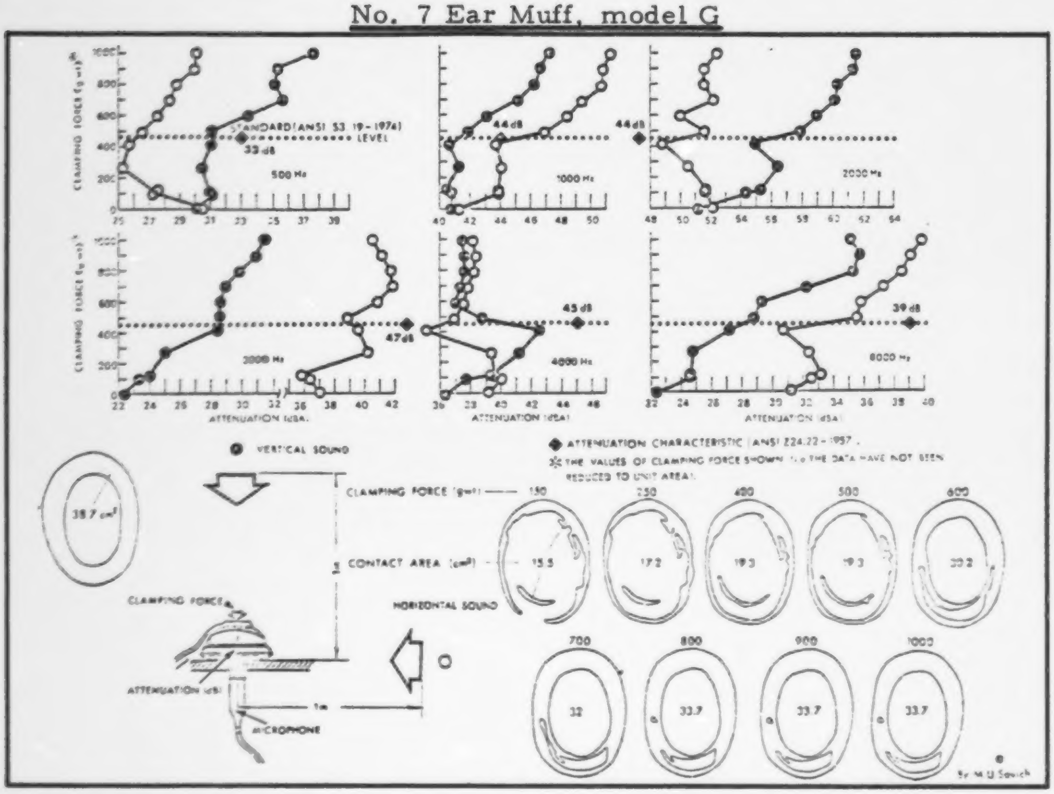
No. 5 Ear Muff, model E



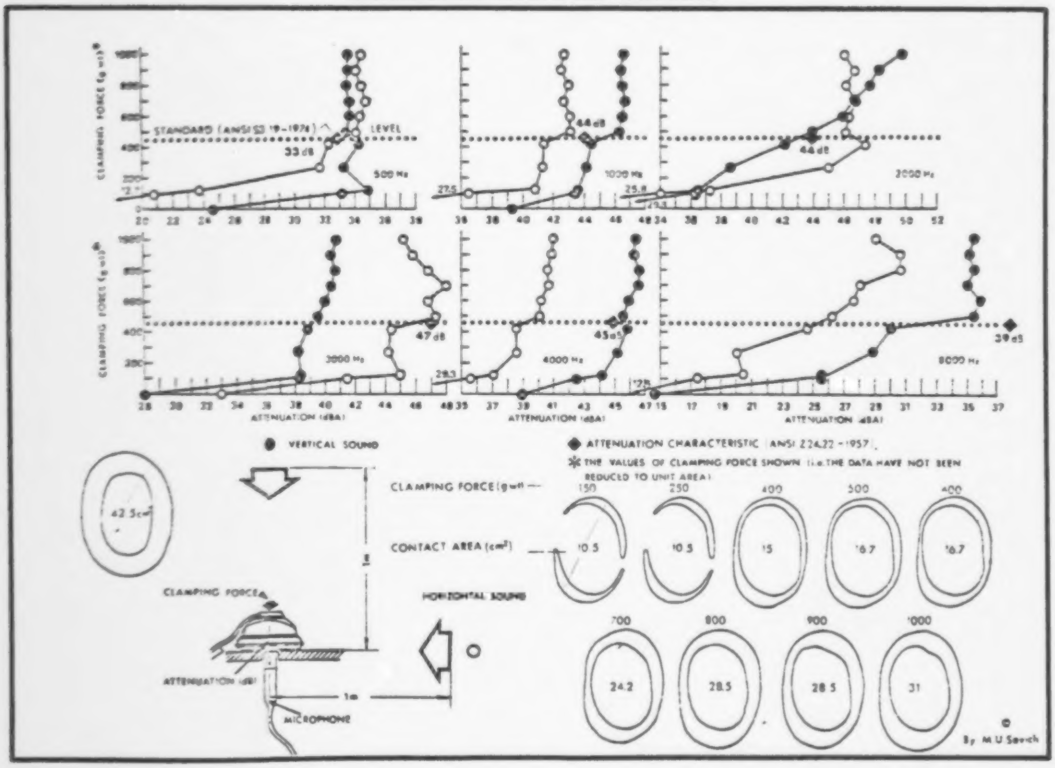
No. 6 Ear Muff, model F



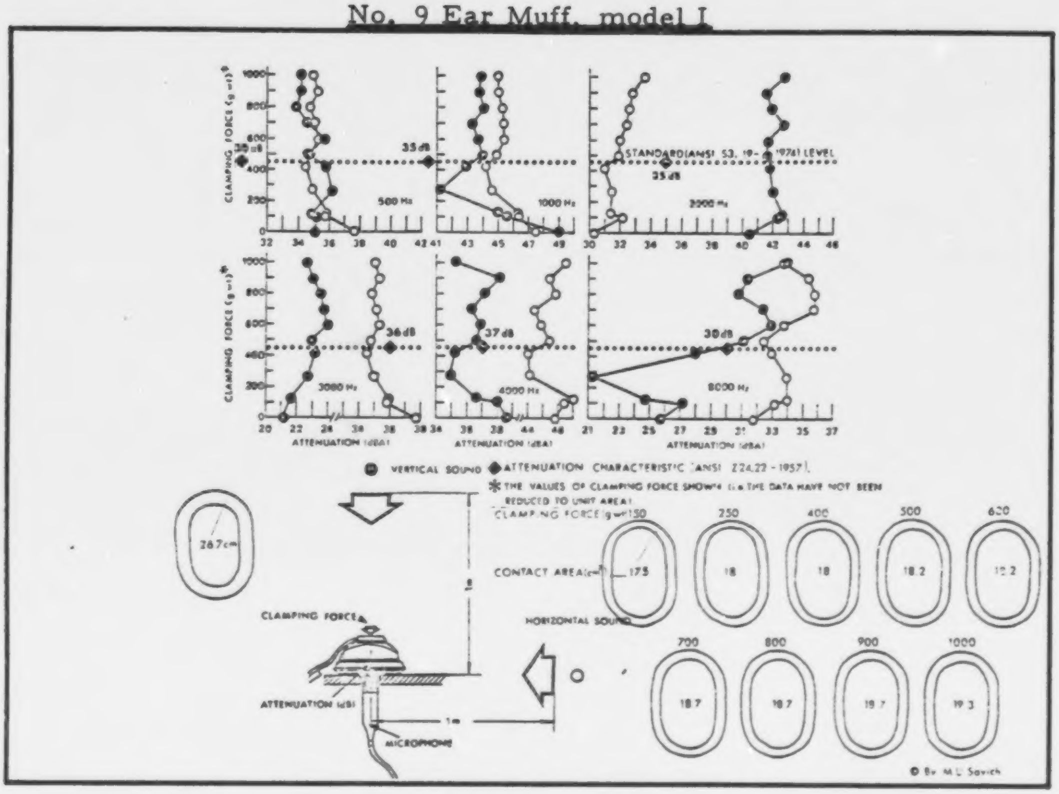
No. 7 Ear Muff, model G



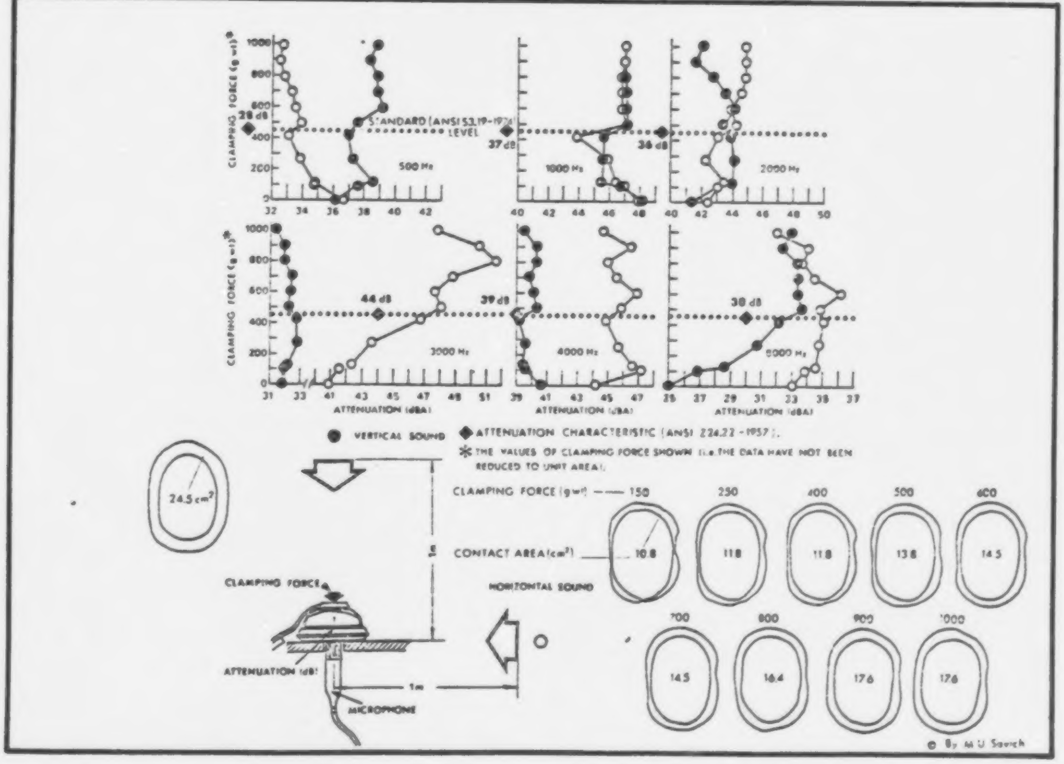
No. 8 Ear Muff, model H



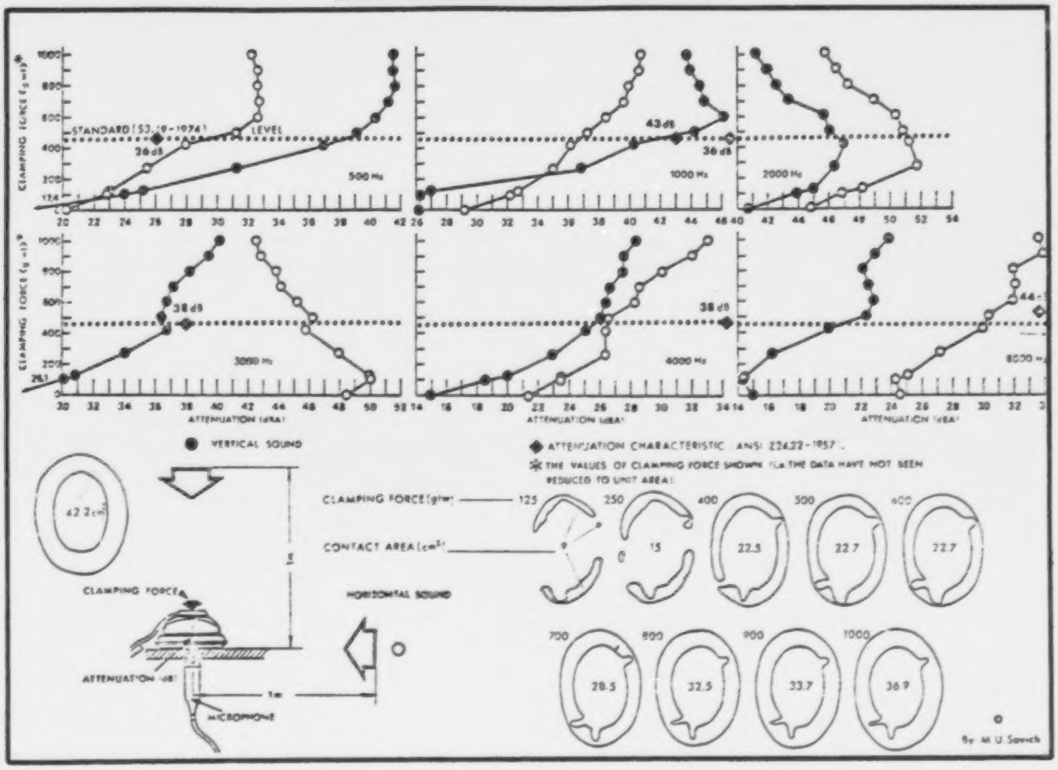
No. 9 Ear Muff, model I



No. 10 Ear Muff, model J



No. 11 Ear Muff, model K



Vignette

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VOL. 2 Report 5

78-74 M. Savich

Noise reduction evaluation of

ear muffs

1978

ÉVALUATION DE LA RÉDUCTION DU BRUIT PAR LES CASQUES ANTIBRUIT

par

M. Savich*

RÉSUMÉ

Le choix des casques antibruit est fondé sur leurs caractéristiques d'atténuation et sur le type de bruit dans les mines.

Pour évaluer la réduction du bruit, on utilise principalement deux méthodes : théorique et par approximation. On compare ensuite les résultats de l'évaluation avec des mesures pratiques effectuées dans des mines.

Les résultats de nos mesures nous permettent de conclure que ce ne sont pas toujours les casques antibruit qui possèdent les meilleures caractéristiques d'atténuation qui permettent une plus grande réduction du bruit.

Mots-clés : Bruit, casque antibruit, atténuation, réduction du bruit, évaluation du bruit.

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NOISE REDUCTION EVALUATION OF EAR MUFFS

by

M. Savich*

ABSTRACT

The selection of ear muffs is done according to their attenuation characteristics and the type of noise in mines.

Noise reduction evaluation is mainly carried out using two methods: theoretical and by approximation. Evaluation results are compared with the practical measurements in mines.

By analyzing the results from our measurements, we see that, in practice the greatest noise reduction is not always given by ear muffs which have the best attenuation characteristics.

Key words: Noise, Ear muffs, Attenuation, Noise reduction, Noise Evaluation.

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1. INTRODUCTION

Throughout Canadian mines, ear muffs are in common use. When purchasing ear muffs, the need to make a selection arises. This selection is done according to ear muff attenuation characteristics and the type of noise in mines. Noise reduction evaluation is mainly carried out using two methods: theoretical and by approximation. Evaluation results are compared with practical results from ear muff efficiency measurements in mines. On the basis of differences in results, an investigation is being carried out and wearing faults, as well as manufacturers' imperfections, are being eliminated.

2. STANDARD METHOD FOR THE MEASUREMENT OF THE ATTENUATION OF EAR MUFFS

Attenuation data are provided by manufacturers who have had their ear muffs tested according to the American National Standards Institute (ANSI) standard Z24.22-1957 "Method for the Measurement of the Real-Ear Attenuation of Ear Protectors at Threshold". This standard is still in use. Recently a new standard ANSI 3.19-1974, "Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Ear Muffs", has been published which is a revision of the ANSI Z24.22-1957 standard. The principal changes are the substitution of narrow bands (third octave bands) of noise instead of discrete tones as the test stimuli, the replacement of an anechoic test room by a reverberant room, and the inclusion of the physical method for production testing and engineering design for ear muffs. This standard is not appropriate to the evaluation of hearing-protective devices designed to operate exclusively against impulsive noise. Apparatus for the measurement of the headband force is described also. Test results are expressed by means and standard deviations of the attenuation data for each frequency specified in both standards. Ear muff device force measurement data shall be reported along with real-ear protection data.

Measurements shall be made on not less than ten randomly selected subjects with normal hearing. The test shall be taken with and without the ear protector, on no less than three separate occasions, at each test frequency. The differences with and without protectors are taken to measure the protector's attenuation. Attenuation values are measured under best fitting conditions in the laboratory.

3. ATTENUATION CONTROL OF EAR MUFFS IN THE WORKPLACE

The attenuation data, expressed in terms of the means and standard deviations, can be used by the user to evaluate the noise reduction capabilities of the hearing protectors. Calculations involving the direct use of these data are relatively lengthy, and they require that octave band sound pressure level measurement data be recorded from exposure areas. Several methods have been proposed that would simplify the calculations necessary for the user of hearing protectors. Evaluation through four methods has been proven:

a) One proven theoretical method for calculating a single number rating of attenuation efficiency of hearing protectors; and

b) Three proven approximate methods which tend to considerably over or under-estimate the attenuation produced by hearing protectors. Their information value is not equivalent to that of precise calculation.

Application of a safety coefficient could improve the reliability of approximate methods.

3.1. Noise Reduction Evaluation - Theoretical Method

The noise reduction rating of hearing protectors is based on the transmission loss in nine octave band centre frequencies (Hz) (1). The method involves calculating the noise reduction in the A-weighted sound level as follows (Table 1):

1) Calculate the A-weighted sound level (L_1) of the untreated noise from its octave band centre frequency (Hz);
2) Calculate the A-weighted sound level (L_2) of the treated noise from its octave band centre frequency (Hz) components, which are the respective octave band attenuations provided by No. 1, ear muff, model A (Table 3); and
3) Subtract L_2 from L_1:

Theoretical Noise Reduction (dBA) $= L_1 - L_2$.

A computer program is included to calculate the 26.9 dBA noise reduction in the same way that it was calculated by long hand (Appendix 2). The data format of the program did not have to be modified when the untreated noise was not measured in the first two octave bands (31.5 and 63 Hz). At octave band frequencies of 31.5 Hz and 63 Hz an entry must be

TABLE 1

A Method for Calculating a Single Number Rating of Noise Attenuating Ear Muffs (See Table 2)

Frequency (Hz)	Noise Level of Jumbo (Three Drills) (dB)	Attenuation ANSI Z24. 22-1957 (dB)	Treated Noise Level (dB)
31. 5	89	-	-
63	100	-	-
125	109	9. 7	99. 3
250	109	16. 1	92. 9
500	109	24. 9	84. 1
1000	107	33. 9	73. 1
2000	108. 5	34. 1	74. 4
4000	109. 5	38. 5	71
8000	106	32. 7	73. 3

Step 1: The A weighted sound level (L_1) of the untreated noise in dBA.

Frequency (Hz)	Noise Level of Jumbo (Three Drills) (dB)	A-Weighting (dB)	Weighted Level (dB)	Antilog (Weighted Level / 10)
31. 5	89	-39. 4	49. 6	0.0009×10^8
63	100	-26. 2	73. 8	0.2399×10^8
125	109	-16. 1	92. 9	19.4984×10^8
250	109	- 8. 6	100. 4	109.6478×10^8
500	109	- 3. 2	105. 8	380.1894×10^8
1000	107	0	107	501.1872×10^8
2000	108. 5	+ 1. 2	109. 7	933.2543×10^8
4000	109. 5	+ 0. 9	110. 4	1096.4782×10^8
8000	106	- 1. 2	104. 8	301.9952×10^8
			Σ	3342.4913×10^8

$L_1 = 10 \log \Sigma = 115.24$ dBA

Step 2: The A-weighted sound level (L_2) of the treated noise in dBA.

Frequency (Hz)	Treated Noise Level (dB)	A-Weighting (dB)	Weighted Level (dB)	Antilog (Weighted Level / 10)
125	99. 3	-16. 1	83. 2	2.0893×10^8
250	92. 9	- 8. 6	84. 3	2.6915×10^8
500	84. 1	- 3. 2	80. 9	1.2303×10^8
1000	73. 1	0	73. 1	0.2042×10^8
2000	74. 4	+ 1. 2	73. 2	0.2089×10^8
4000	71	+ 0. 9	70. 1	0.1023×10^8
8000	73. 3	- 1. 2	72. 1	0.1622×10^8
			Σ	6.6887×10^8

$L_2 = 10 \log \Sigma = 88.25$ dBA

Noise Reduction = $L_1 - L_2 = 26.99$ dBA

TABLE 2

Noise Surveys in Mines

Measured at the Operator's Ears	Frequency (Hz)									dBA*
	31.5	63	125	250	500	1k	2k	4k	8k	
Jumbo (Three Drills)	89	100	109	109	109	107	108.5	109.5	106	115.24
Drill Hydrofore	68	79	86	99	96	99	99	99	94	105.2
Jaw Crusher	89	94	94.5	94.5	94.5	94.5	94	97	88	101.64

* Total noise estimated from the octave-band noise levels given in the first nine columns (Appendix 1)

made of a very small number which has no influence on the evaluation of noise levels in dBA (Fig. 1). Difference in noise between 125 Hz and 31.5 Hz or 63 Hz should be less by 20 dB (compare Appendix 2 with Fig. 1).

The proposed method is not limited to ear protectors. It can be applied to determine the noise reduction of acoustical enclosures, the installation of acoustical absorptive material in a particular room, etc.

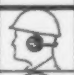
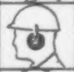
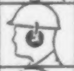
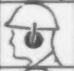
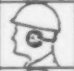
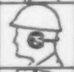
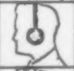
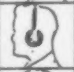
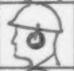
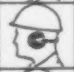
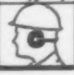
3.2. Approximate Methods for Calculating Noise Reduction

Published references, such as those of the American National Standards Institute and the American National Institute of Occupational Safety and Health (NIOSH), provide information for selecting hearing-protective devices (2) (3). A proposed regulation requires that any hearing protector used by an employee shall reduce the effective noise level to less than 90 dBA (OSHA). This regulation suggests three methods for determining the noise reduction (R), given in sections 1, 2 and 3 below.

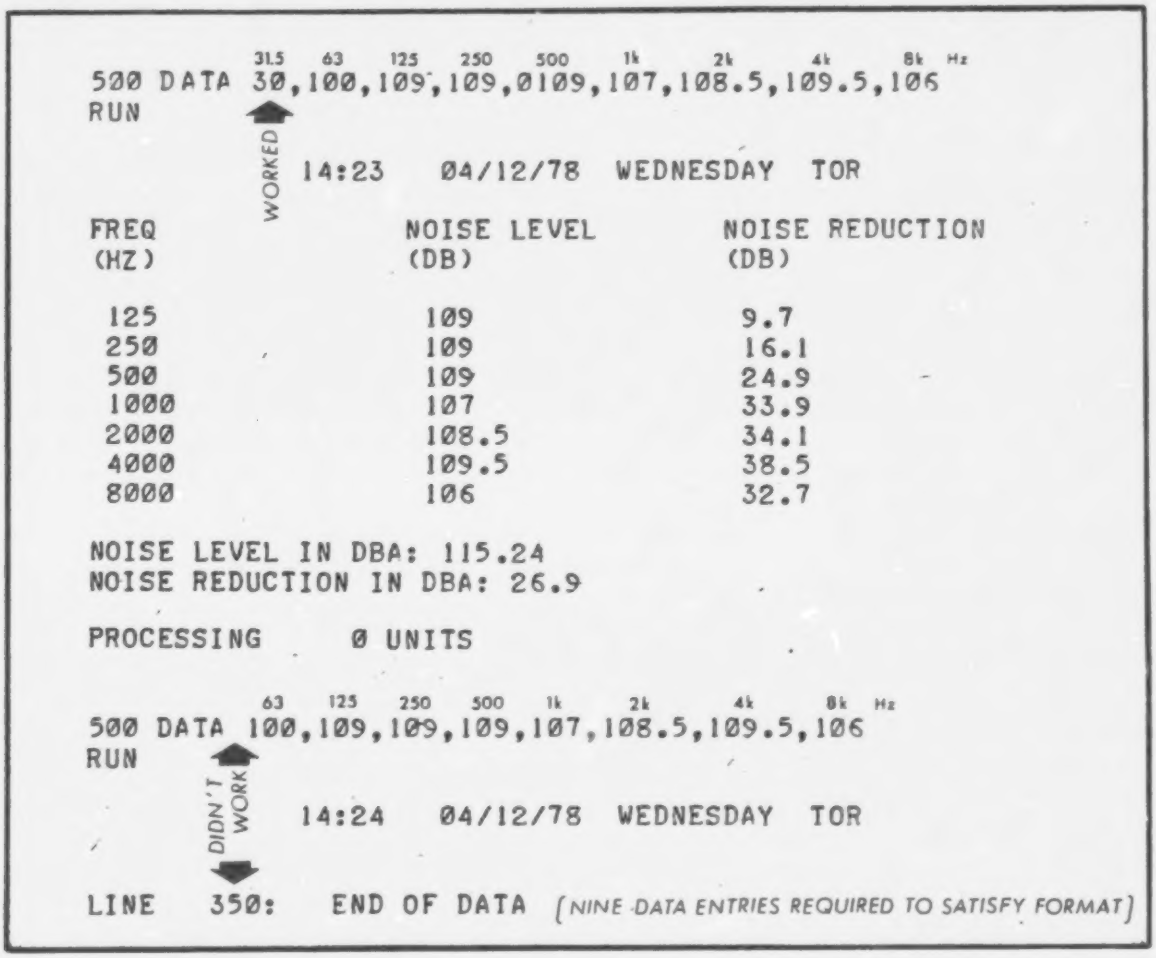
The determination of R is based on a knowledge of the attenuation

TABLE 3

Attenuation Characteristics of Typical Ear Muffs

No.	Ear Muff	Band	Characteristic	Attenuation (dB)*								
				Frequency in Hertz								
				125	250	500	1k	2k	3k	4k	6k	8k
1	A		Measured	9.7	16.1	24.9	33.9	34.1	36.0	41.0	33.8	31.5
			Std. Dev.	3.2	2.5	2.8	5.1	2.9	5.6	5.7	6.6	5.9
2	B		Measured	5	13	22	31	31	41	36	28	21
			Std. Dev.	-	-	-	-	-	-	-	-	-
3	C		Measured	10	16	30	34	37	41	45	39	34
			Std. Dev.	-	-	-	-	-	-	-	-	-
4	D		Measured	11.5	16.5	26.5	36.5	38	38.5	44.5	39.5	-
			Std. Dev.	-	-	-	-	-	-	-	-	-
5	E		Measured	13.4	17.3	28.6	41.8	40.7	45.2	42.7	32.6	29.3
			Std. Dev.	3.3	3.9	3.0	3.4	5.6	4.6	5.3	4.1	4.7
6	F		Measured	17	18	29	36	38	44	44	43	43
			Std. Dev.	2.6	2.6	3.1	3.2	4.1	7.2	4.6	4.7	5.7
7	G		Measured	18	23	33	44	44	47	45	42	39
			Std. Dev.	-	-	-	-	-	-	-	-	-
8	H		Measured	18	23	33	44	44	47	45	42	39
			Std. Dev.	-	-	-	-	-	-	-	-	-
9	I		Measured	12	17	30	35	35	36	37	32	30
			Std. Dev.	2.5	3.0	4.6	5.6	4.5	4.3	4.2	4.1	2.9
10	J		Measured	10	17	28	37	36	44	39	32	30
			Std. Dev.	2.0	2.6	4.3	5.4	4.5	5.6	3.8	5.4	4.9
11	K		Measured	15	17	26	43	36	38	38	33	34
			Std. Dev.	5.2	3.9	8.8	3.6	4.9	6.6	6.8	1.3	5.3
Σ	Arithmetic Mean of all Ear Muffs			12.16	17.09	27.8	37.22	36.98	41.07	41.22	35.49	33.53
	Std. Dev.			3.86	2.47	3.09	4.31	3.58	3.9	3.49	5.0	7.36

* Attenuation characteristic measured in accordance with American National Standard Specification Z.24.22-1957 (from Factory Data).



```
          31.5  63   125   250   500    1k     2k      4k     8k  Hz
500 DATA 30,100,109,109,0109,107,108.5,109.5,106
RUN
          WORKED
           14:23    04/12/78  WEDNESDAY  TOR

FREQ              NOISE LEVEL      NOISE REDUCTION
(HZ)              (DB)             (DB)

 125               109              9.7
 250               109              16.1
 500               109              24.9
 1000              107              33.9
 2000              108.5            34.1
 4000              109.5            38.5
 8000              106              32.7

NOISE LEVEL IN DBA: 115.24
NOISE REDUCTION IN DBA: 26.9

PROCESSING     0 UNITS

          63   125  250   500  1k    2k     4k    8k  Hz
500 DATA 100,109,109,109,107,108.5,109.5,106
RUN
        DIDN'T
        WORK
           14:24    04/12/78  WEDNESDAY  TOR

LINE   350:   END OF DATA  [NINE DATA ENTRIES REQUIRED TO SATISFY FORMAT]
```

Fig. 1: Computer printout illustrating results from calculations; with a frequency of 31.5 Hz and only 30 dB, and without this frequency. (Compare with Appendix 2).

of the ear protectors in octave bands and an A-slow sound level analysis of the noisy environment. The pure tone attenuation vs. frequency characteristics of the ear protector (normally supplied by the manufacturer) should be determined in accordance with standards ANSI Z24.22-1957 or ANSI S3.19-1974. The standards prescribe the bands with the following centre frequencies: 125, 250, 500, 1000, 2000, 3000 (3150), 4000, 6000 (6300) and 8000 Hz. We will also assume that the 4000 Hz octave band attenuation level can be obtained by averaging the pure tone attenuation levels at 3000 and 4000 Hz, and that the 8000 Hz octave band attenuation level can be obtained by averaging the pure tone attenuation levels at 6000 and 8000 Hz.

3.2.1. Method 1

The procedure to determine the dBA reduction (R):

$$R = L_A - 10 \log S \qquad \text{(Eq. 1)}$$

where R = dBA - reduction factor

L_A = workplace dBA noise level

$$\begin{aligned} S = {} & \text{antilog}\,[0.1 \times (L_1 - Q_1)] + \text{antilog}\,[0.1 \times (L_2 - Q_2)] \\ & + \text{antilog}\,[0.1 \times (L_3 - Q_3)] + \text{antilog}\,[0.1 \times (L_4 - Q_4)] \\ & + \text{antilog}\,[0.1 \times (L_5 - Q_5)] + \text{antilog}\,[0.1 \times (L_6 - Q_6)] \\ & + \text{antilog}\,[0,1 \times (L_7 - Q_7)] \end{aligned}$$

where L_1, L_2, ..., L_7 denote the octave band levels in dB at 125, 250, 500, 1000, 2000, 4000, and 8000 Hz respectively, and for the evaluation of the pure tone attenuation supplied by the manufacturer:

Let Q_1, Q_2, ..., Q_7 be defined (in dB) as follows:

Q_1 = attenuation at 125 Hz, plus 16.1 dB, minus 2 x (standard deviation)

Q_2 = attenuation at 250 Hz, plus 8.6 dB, minus 2 x (standard deviation)

Q_3 = attenuation at 500 Hz, plus 3.2 dB, minus 2 x (standard deviation)

Q_4 = attenuation at 1000 Hz, minus 2 x (standard deviation)

Q_5 = attenuation at 2000 Hz, minus 1.2 dB, minus 2 x (standard deviation)

Q_6 = average of attenuation at 3000 and 4000 Hz, minus 0.9 dB, minus standard deviation at 3000 Hz, minus standard deviation at 4000 Hz

Q_7 = average of attenuations at 6000 and 8000 Hz, minus standard deviation at 6000 Hz, minus standard deviation at 8000 Hz.

The numbers + 16.1, + 8.6, +3.2, 0, - 1.2, - 0.9 represent the A-weighting relative response at the indicated octave band centre frequencies.

Evaluation

Ear muff Model 1675, American Optical, U.S.A. was used in a working area with a noise level of 115.24 dBA (Jumbo-three drills) and octave band noise levels of:

125	250	500	1000	2000	4000	8000 Hz
109	109	109	107	108.5	109.5	106 dB

and the ear muff had the following attenuation characteristics (ANSI Z.24.22-1957):

	125	250	500	1000	2000	3000	4000	6000	8000	Hz
Mean Attenuation	9.7	16.1	24.9	33.9	34.1	36.0	41.0	33.8	31.5	dB
Std. Dev.	3.2	2.5	2.8	5.1	2.9	5.6	5.7	6.6	5.9	
						38.5		32.65		

The "Q" and "L-Q" values in S are:

$Q_1 = 9.7 + 16.1 - (2 \times 3.2) = 19.4 \quad (L_1 - Q_1) = 109 - 19.4 = 89.6$

$Q_2 = 16.1 + 8.6 - (2 \times 2.5) = 19.7 \quad (L_2 - Q_2) = 109 - 19.7 = 89.3$

$Q_3 = 24.9 + 3.2 - (2 \times 2.8) = 22.5 \quad (L_3 - Q_3) = 109 - 22.5 = 86.5$

$Q_4 = 33.9 - (2 \times 5.1) = 23.7 \quad (L_4 - Q_4) = 107 - 23.7 = 83.3$

$Q_5 = 34.1 - 1.2 - (2 \times 2.9) = 27.1 \quad (L_5 - Q_5) = 108.5 - 27.1 = 81.4$

$Q_6 = 38.5 - 0.9 - 5.6 - 5.7 = 26.3 \quad (L_6 - Q_6) = 109.5 - 26.3 = 83.2$

$Q_7 = 32.7 + 1.2 - 6.6 - 5.9 = 21.4 \quad (L_7 - Q_7) = 106 - 21.4 = 84.6$

Applying the formula for the dBA reduction factor:

$$R = L_A - 10 \log S$$

where $L_A = 115.24$ dBA

and

$$\begin{aligned} S &= \text{antilog}\,(0.1 \times 89.6) + \text{antilog}\,(0.1 \times 89.3) \\ &+ \text{antilog}\,(0.1 \times 86.5) + \text{antilog}\,(0.1 \times 83.3) \\ &+ \text{antilog}\,(0.1 \times 81.4) + \text{antilog}\,(0.1 \times 83.2) \\ &+ \text{antilog}\,(0.1 \times 84.6) \\ &= 912{,}010{,}836 + 851{,}138{,}037 + 446{,}683{,}590 \\ &+ 213{,}796{,}208 + 138{,}038{,}427 + 208{,}929{,}612 \\ &+ 288{,}403{,}151 \\ &= 3{,}058{,}999{,}861 \end{aligned}$$

$$\begin{aligned} R &= 115.24 - 10 \log (3{,}058{,}999{,}861) = 115.24 - 94.86 \\ &= 20.38 \text{ dBA} \end{aligned}$$

The effective level is:

$$L_A - R = 115.24 - 20.38 = 94.86 \text{ dBA}$$

This calculation should be simplified as shown in Table 4.

Discussion

The R factor calculated by this method incorporates an adjustment to account for statistical variation. It is the most precise method.

3.2.2. Method 2

This method has been formulated concisely by the Recommended Noise Standard, and includes subtraction of 10 dB to account for possible noise spectrum irregularities and noise leakage which might be caused by long hair, safety glasses, head movement, etc. The procedure to determine

TABLE 4

Noise Reduction Calculation Example

Octave Band Measurements		Modifying Factors for Noise Reduction			
Centre Frequency	SPL dB B	A-Weighting Factor A	2σ C	Ear Muff Attenuation D	Resultant Noise at Ear B+A+C-D
125	109	-16.1	6.4	9.7	89.6
250	109	- 8.6	5	16.1	89.3
500	109	- 3.2	5.6	24.9	86.5
1000	107	0	10.2	33.9	83.3
2000	108.5	+ 1.2	5.8	34.1	81.4
4000	109.5	+ 0.9	11.3	38.5	83.2
8000	106	- 1.2	12.5	32.7	84.6
	115.24 dBA*			$10 \log_{10}$ Sum = 94.86 dBA	

Noise Reduction Factor = 115.24 - 94.86 = 20.38 dBA

* See Program in Appendix 1.

dBA (R): $R = L_A - 10 \log S - 10.0$ (Eq. 2)

where R = dBA - reduction factor

L_A = workplace dBA noise level

10.0 is the correction factor

$S = \text{antilog}\,[0.1 \times (L_1 - Q_1)] + \ldots + \text{antilog}\,[L_7 - Q_7)]$

where L_1, L_2, ..., L_7 denote octave band levels in dB at 125, 250, 500, 1000, 2000, 4000, and 8000 Hz respectively, and Q_1 Q_2, ..., Q_7 denote the attenuation data supplied by the manufacturer including the A-weighting network at the indicated octave band centre frequencies.

Evaluation

The same ear muff and the same working area as in Method 1 was used:

$Q_1 = 9.7 + 16.1 = 25.8 \qquad (L_1 - Q_1) = 109 - 25.8 = 83.2$

$Q_2 = 16.1 + 8.6 = 24.7 \qquad (L_2 - Q_2) = 109 - 24.7 = 84.3$

$Q_3 = 24.9 + 3.2 = 28.1 \qquad (L_3 - Q_3) = 109 - 28.1 = 80.9$

$Q_4 = 33.9 = 33.9 \qquad (L_4 - Q_4) = 107 - 33.9 = 73.1$

$Q_5 = 34.1 - 1.2 = 32.9 \qquad (L_5 - Q_5) = 108.5 - 32.9 = 75.6$

$Q_6 = 38.5 - 0.9 = 37.6 \qquad (L_6 - Q_6) = 109.5 - 37.6 = 71.9$

$Q_7 = 32.7 + 1.2 = 31.5 \qquad (L_7 - Q_7) = 106 - 31.5 = 74.5$

Applying the formula for the dBA reduction factor,

$$R \approx L_A - 10 \log S - 10.0$$

where $L_A \approx 115.24$ dBA

and

$$\begin{aligned} S \approx\ & \text{antilog } (0.1 \times 83.2) + \text{antilog } (0.1 \times 84.3) \\ & + \text{antilog } (0.1 \times 80.9) + \text{antilog } (0.1 \times 73.1) \\ & + \text{antilog } (0.1 \times 75.6) + \text{antilog } (0.1 \times 71.9) \\ & + \text{antilog } (0.1 \times 74.5) \\ =\ & 208{,}929{,}612 + 269{,}153{,}479 + 123{,}026{,}877 \\ & + 20{,}417{,}379 + 36{,}307{,}805 + 15{,}488{,}166 \\ & + 28{,}183{,}829 = 701{,}507{,}147 \end{aligned}$$

$$\begin{aligned} R &= 115.24 - 10 \log (701{,}507{,}147) - 10.0 \\ &= 115.24 - 88.46 - 10.0 = 16.78 \text{ dBA} \end{aligned}$$

The effective dBA level is:

$$L_A - R = 115.24 - 16.78 = 98.46 \text{ dBA}$$

Discussion:

This method is similar to Method 1 except that 2σ (2 x standard deviation) is not subtracted from Q. This method includes subtraction of 10 dB to account for possible noise spectrum irregularities and noise leakage which might be caused by long hair, safety glasses, head movement, etc.

3.2.3. Method 3

If the octave band levels of the noise are not known, then the dBA reduction R may be computed simply:

$$R = -10 \log S - 3.0 \qquad \text{(Eq. 3)}$$

where R = dBA - reduction factor

$S = \text{antilog}(-0.1 \times Q_1) + \ldots + \text{antilog}(-0.1 \times Q_7)$

3.0 is the correction factor

Evaluation:

The same ear muff was used as in Method 1 and Method 2. The "Q" value is the same as in Method 2. Applying the formula for the dBA reduction factor:

$$R = -10 \log S - 3.0$$

where $S = \text{antilog}(-2.58^{*}) + \text{antilog}(-2.47) + \text{antilog}(-2.81)$

$+ \text{antilog}(-3.39) + \text{antilog}(-3.29) + \text{antilog}(-3.76)$

$+ \text{antilog}(-3.15)$

---

* $\text{antilog}(-2.58) = \text{antilog}(7.42 - 10)$

$= \text{antilog}\ \bar{3}.42$

$= 0.00263 + 0.00339 + 0.00155 + 0.00014$

$+ 0.00051 + 0.00017 + 0.00071 = 0.00937$

$$R = -10 \log 0.00937 - 3.0 = 20.28 - 3.0 = 17.28 \text{ dBA}$$

The effective dBA level is:

$$L_A - R = 115.24 - 17.28 = 97.96 \text{ dBA}$$

Discussion:

This calculation is approximate, and is based upon the assumption that the octave band levels are equal. For most types of noise it will give results close to those obtained by the more accurate Method 2, above.

4. COMPARISON OF CALCULATION METHODS

Several methods were developed to determine dBA reduction (R) for ear protectors. J. Botsford's method is based on "sound level conversion" (3). The reduction factor (R) is computed by using the attenuation data of a hearing protector and a single noise spectrum, which is composed of equal sound pressure levels for the median octave bands found in major industries in the U. S. A.

Three computational approximate methods show three different R factors for the same ear muff (Table 5). Fairly close agreement was shown between the 2nd and 3rd Approximate Methods. Results from the 1st Method are higher. Generally, there is no agreement between measured results and Approximate Methods of noise reduction evaluation, except No. 5, Ear Muff - E and No. 10 Ear Muff - J. Some agreement exists between No. 2, Ear Muff - B and No. 6, Ear Muff - F. The noise reduction (attenuation) was calculated by the theoretical method because the results can be easily compared with EPA's* proposed hearing protector regulations (4). EPA established the framework for labeling hearing protector products (Fig. 2).

---

* Environmental Protection Agency.

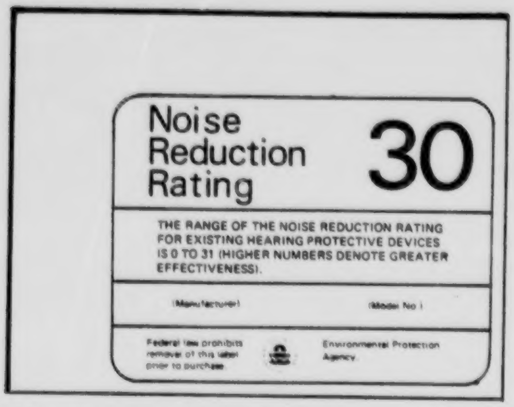
TABLE 5

Comparison of Noise Reduction Factors of Ear Muffs by Different Evaluation Methods

No.	Ear Muff	Band	Noise Reduction - dBA																				
			Measured*				Approximate Methods												Theoretical Method			
			Jumbo Operatr	Hydro. Operatr	Crusher Operatr	Σ/3	Jumbo Operator				Hydrofore Operator				Crusher Operator				Jumbo Operatr	Hydro. Operatr	Crusher Operatr	Σ/3
							1^+	2^+	3^+	Σ/3	1^+	2^+	3^+	Σ/3	1^+	2^+	3^+	Σ/3				
1	A		18.6	12.6	15	15.4	20.38	16.78	17.28	18.15	22.71	18.71	17.28	19.57	21.16	17.65	17.28	18.70	26.9	28.8	27.7	27.8
2	B		16.5	12	11.3	13.3	-	13.08	13.50	13.29	-	15.52	13.50	14.51	-	14.06	13.50	13.78	23.1	25.5	24.1	24.2
3	C		11.5	8	10.3	9.9	-	17.73	18.35	18.04	-	19.56	18.35	18.95	-	18.54	18.35	18.44	27.8	29.6	28.6	28.7
4	D		13.6	10.5	12	12	-	18.20	18.87	18.53	-	19.90	18.87	19.38	-	19.02	18.87	18.94	28.2	29.9	29	29
5	E		25.7	25.3	18.8	23.3	21.95	19.22	19.85	20.34	23.21	20.89	19.85	21.32	22.97	20.45	19.85	21.09	29.4	30.9	30.4	30.2
6	F		8.6	24.6	23.8	19	24.67	20.62	21.17	22.15	25.43	21.38	21.17	22.66	25.35	21.33	21.17	22.62	30.6	31.4	31.3	31.1
7	G		-	-	-	-	-	(25.07)	(25.66)	(25.36)	-	(27.04)	(25.66)	(26.35)	-	(25.91)	(25.66)	(25.78)	(34.6)	(36.3)	(35.4)	(35.4)
8	H		-	-	-	-	-	(25.07)	(25.66)	(25.36)	-	(27.04)	(25.66)	(26.35)	-	(25.91)	(25.66)	(25.78)	(34.6)	(36.3)	(35.4)	(35.4)
9	I		3.2	5.8	8.3	5.8	24.81	18.48	18.94	20.74	24.73	19.9	18.94	21.19	25	19.29	18.94	21.08	28.5	29.9	29.3	29.2
10	J		25	18.2	23.1	22.1	21.67	18.30	18.44	19.47	23.19	20.11	18.44	20.58	22.62	18.85	18.44	19.97	27.9	30.1	28.9	29
11	K		11.8	10	16	12.6	22.26	19.02	19.49	20.26	23.81	20.09	19.49	21.13	22.76	19.74	19.49	20.66	29	30.2	29.8	29.7
Σ-(7+8)	Arithmetic Mean		14.94	14.11	15.40	14.82	22.62	17.94	18.43	19.00	23.85	19.56	18.43	19.92	23.31	18.77	18.43	19.48	27.93	29.59	28.79	28.77
	Std. Dev.		7.38	7.03	5.55	5.74	1.76	2.11	2.14	2.53	1.04	1.69	2.14	2.33	1.58	2.07	2.14	2.53	2.10	1.70	2.04	1.95

Note: * In mines.

+ Method.



Noise Reduction Rating 30

THE RANGE OF THE NOISE REDUCTION RATING FOR EXISTING HEARING PROTECTIVE DEVICES IS 0 TO 31 (HIGHER NUMBERS DENOTE GREATER EFFECTIVENESS).

(Manufacturer) (Model No.)

Federal law prohibits removal of this label prior to purchase

Environmental Protection Agency

Fig. 2: Sample of proposed label.

The label on the product will bear a number from 0 - 31. The higher the number, the greater the product's effectiveness in attenuating noise. Regulations for these products will be developed from the proposed General Provisions and Hearing Protector Regulations and will be announced in the Federal Register.

To investigate the differences between laboratory test attenuation data, a new field test method for ear muffs has been developed in the Elliot Lake Laboratory.

5. CONCLUSION

By analyzing the results from our measurements, we see that, in practice, the greatest noise reduction is not always given by ear muffs which have the best attenuation characteristics. When purchasing ear muffs, practical attenuation results should be taken into account. Many other factors affect the increase or decrease of attenuation.

6. ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Mines Accident Prevention Association of Ontario for providing a selection of ear muffs for this project. He is also indebted to E. D. Dainty, Dr. R. Tervo and G. Knight who were helpful in many ways. Grateful acknowledgement is given to A. Webster who transcribed and completed the tables from the raw data.

7. REFERENCES

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2. "Recommended standard for occupational noise exposure"; Sound and Vibration J; vol 6, no. 11; Nov 1972.
3. Kroes, P., Roy, F. and Lempert, B. "List of personal hearing protectors"; Publication no. (NIOSH) 76-120.
4. "EPA to label hearing protectors"; National Safety News; 86; July 1977.

Program

Calculate A-Weighted Sound Level from Octave Band Levels Using a Hewlett-Packard HP-35

Step No.	Enter Data	Operation		Step No.	Enter Data	Operation	
		Enter	Press			Enter	Press
1	$L_{31.5}$	-	ENTER↑	20	-	10	x^y
2	-	39.4	−	21	L_{1k}	-	ENTER↑
3	-	10	÷	22	-	10	÷
4	-	10	x^y	23	-	10	x^y
5	L_{63}	-	ENTER↑	24	L_{2k}	-	ENTER↑
6	-	26.2	−	25	-	1.2	+
7	-	10	÷	26	-	10	÷
8	-	10	x^y	27	-	10	x^y
9	L_{125}	-	ENTER↑	28	L_{4k}	-	ENTER↑
10	-	16.1	−	29	-	0.9	+
11	-	10	÷	30	-	10	÷
12	-	10	x^y	31	-	10	x^y
13	L_{250}	-	ENTER↑	32	L_{8k}	-	ENTER↑
14	-	8.6	−	33	-	1.2	−
15	-	10	÷	34	-	10	÷
16	-	10	x^y	35	-	10	x^y, +
17	L_{500}	-	ENTER↑	36	-	-	LOG
18	-	3.2	−	37	-	10	×
19	-	10	÷				

Note:

Step No. 1, for data beginning at 31.5 Hz octave band.
Step No. 5, for data beginning at 63 Hz octave band.
Step No. 9, for data beginning at 125 Hz octave band.

Computer Program for Calculating the Effective Noise Reduction (Attenuation) of Ear Muffs

```
100 E=LOG(10)
105 A1=0
110 A2=0
120 DIM F(9),L(9),C(9),A(9)
130 F(1)=31.5
140 F(2)=63
150 F(3)=125
160 F(4)=250
170 F(5)=500
180 F(6)=1000
190 F(7)=2000
200 F(8)=4000
210 F(9)=8000
220 C(1)=-39.4
230 C(2)=-26.2
240 C(3)=-16.1
250 C(4)=-8.6
260 C(5)=-3.2
270 C(6)=0
280 C(7)=1.2
290 C(8)=.9
300 C(9)=-1.2
310 FOR I=1 TO 9
320 READ A(I)
330 NEXT I
340 FOR J=3 TO 9
350 READ L(J)
360 A1=A1+EXP(E/10*(A(J)+C(J)-L(J)))
370 A2=A2+EXP(E/10*(A(J)+C(J)))
380 NEXT J
390 A=INT(1000/E*LOG(A2)+.5)/100
400 A0=INT(10*(A-10/E*LOG(A1))+.5)/10
410 PRINT 'FREQ','NOISE LEVEL','NOISE REDUCTION'
420 PRINT '(HZ)','(DB)','(DB)'
430 PRINT
440 FOR K=3 TO 9
450 PRINT F(K),A(K),L(K)
460 NEXT K
470 PRINT
480 PRINT 'NOISE LEVEL IN DBA:';A
490 PRINT 'NOISE REDUCTION IN DBA:';A0
500 DATA 89,100,109,109,109,107,108.5,109.5,106
510 DATA 9.7,16.1,24.9,33.9,34.1,38.5,32.7
```

```
FREQ                NOISE LEVEL          NOISE REDUCTION
(HZ)                (DB)                 (DB)

 125                 109                  9.7
 250                 109                  16.1
 500                 109                  24.9
 1000                107                  33.9
 2000                108.5                34.1
 4000                109.5                38.5
 8000                106                  32.7

NOISE LEVEL IN DBA: 115.24
NOISE REDUCTION IN DBA: 26.9
```

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VoL. 2 Report 6

78-75 M. Savich

The acceptability of ear muffs

1978

ACCEPTABILITÉ DES CASQUES ANTIBRUIT

par

M. Savich*

RÉSUMÉ

Tout dispositif de protection de l'ouïe doit non seulement atténuer le son, mais aussi être accepté par la personne qui le porte et confortable. Certains des principaux problèmes posés par les casques antibruit sont dus au contact entre les coussinets et la tête et à leur conception fonctionnelle. Les essais de confort ont montré que les travailleurs préféraient les casques avec de grands coussinets. Par ailleurs, une étude des diamètres bizygomatiques montre qu'il existe une large gamme de tailles de tête. Toutefois, les casques antibruit étudiés couvrent cette gamme, avec des changements correspondants dans la force de serrage.

Mots-clés : Casque antibruit, confort, diamètre bizygomatique, force de serrage.

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THE ACCEPTABILITY OF EAR MUFFS

by

M. Savich*

ABSTRACT

Any ear-protective device must not only attenuate sound, it also must be acceptable and comfortable to the wearer. Some of the main problems encountered in ear muffs are caused by the ear cushion seal against the head and their functional design. In comfort tests it was demonstrated that ear muffs with large cushion areas were favoured. Also, bizygomatic diameter surveys show that there is a wide range of head sizes. However, commercial ear muffs examined will fit this range with corresponding changes in the clamping force.

Key words: Ear muff, Comfort, Bizygomatic diameter, Clamping force.

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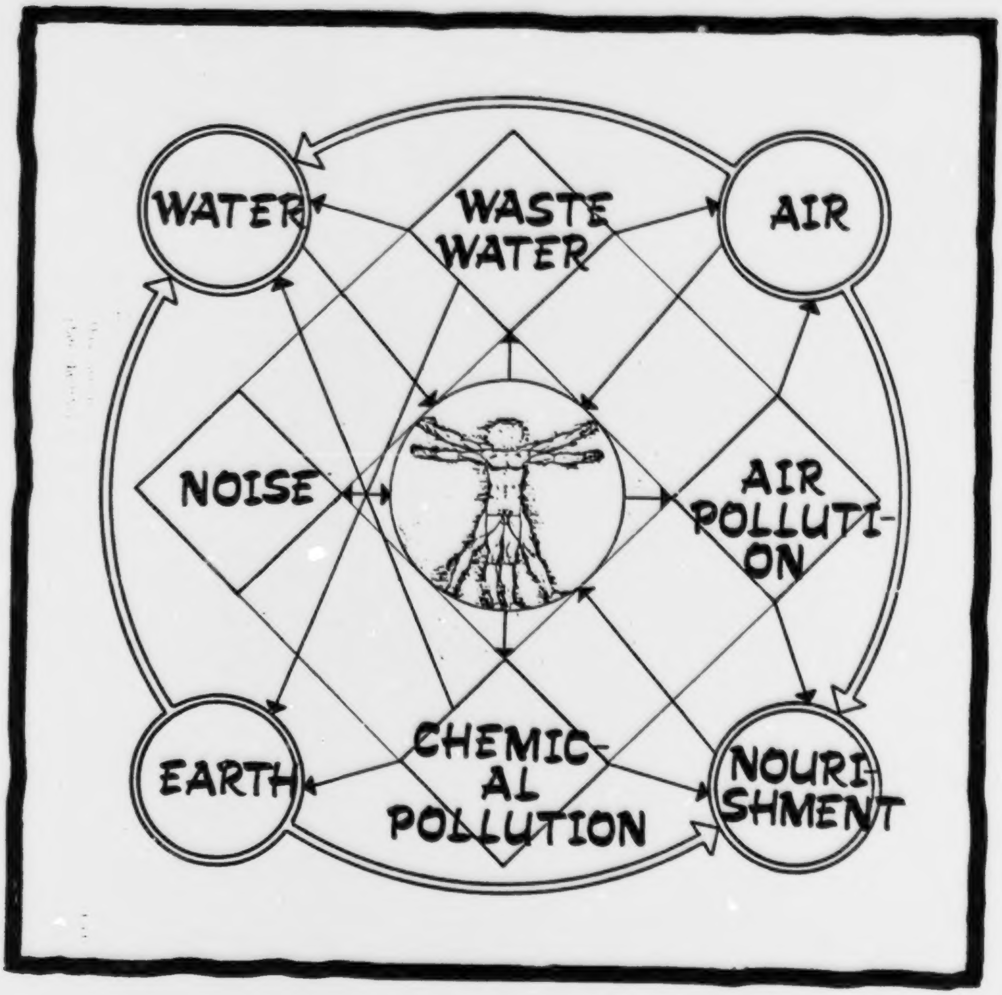

WATER
WASTE WATER
AIR
NOISE
AIR POLLUTION
EARTH
CHEMICAL POLLUTION
NOURISHMENT

Vignette

1. OBJECTIVE

Constant, voluntary use of personal protective equipment, (such as ear plugs and muffs) in all Canadian mines, will guard miners from the threat of hearing loss. Because of this, a new effort has been made to obtain a detailed analysis of ear muffs to improve their application under working conditions.

2. EAR-PROTECTIVE DEVICES

The benefits of reduced noise in mines fall under two categories:

1. The benefits of reduced risk of hearing loss, and
2. The benefits relating to more pleasant working conditions.

There are three basic elements which should be kept in mind in noise and vibration control: a source, a path, and a receiver. The criteria and exposure limits should be established, supplemented and revised regularly in the light of current knowledge and data. The prevention of occupational hazards in the working environment due to noise and vibration should be kept within limits (1) by:

a) technical measures:

b) supplementary administrative measures, where the technical measures alone do not provide sufficient protection.

Where such measures do not make it possible to bring noise and vibration within the limit:

Often the noise level cannot be reasonably reduced at its source or by the use of acoustical materials and noise barriers. In such cases, some form of ear protection should be considered for those people who are exposed to the noise. There are two types of ear-protection devices; earplugs that fit into the external auditory canal, and muffs that cover the entire ear.

3. THE EFFECTIVENESS OF EAR-PROTECTION DEVICES

The effectiveness of ear-protection devices depends on a number of physical and physiological factors: the nature of the noise, the duration of exposure, attenuation characteristics, and possibly other variables. For a person wearing hearing protection, sound energy reaches the inner ear by four different paths (Fig. 1):

1) through bone conduction which in effect short circuits the protector;
2) transmitted by vibration of the protective device;
3) by passing through leaks in the protector (which is minimal); and,
4) in acoustic leaks through or around the protective device.

Ear-protective devices can be divided into four categories (Fig. 2) (2):

1) Ear plugs (inserts) that fit into the ear canal. There are two types: pre-formed (e.g., moulded rubber, plastic, etc.) and non-preformed (e.g., waxed cotton).
2) Semi-inserts that provide an acoustic seal at the entrance to the ear canal and are supported by headset-type bands.
3) Ear muffs or cushions that cover the external ear. In general, there are two types:
    a) foam cushions that fit around the ear and press against the

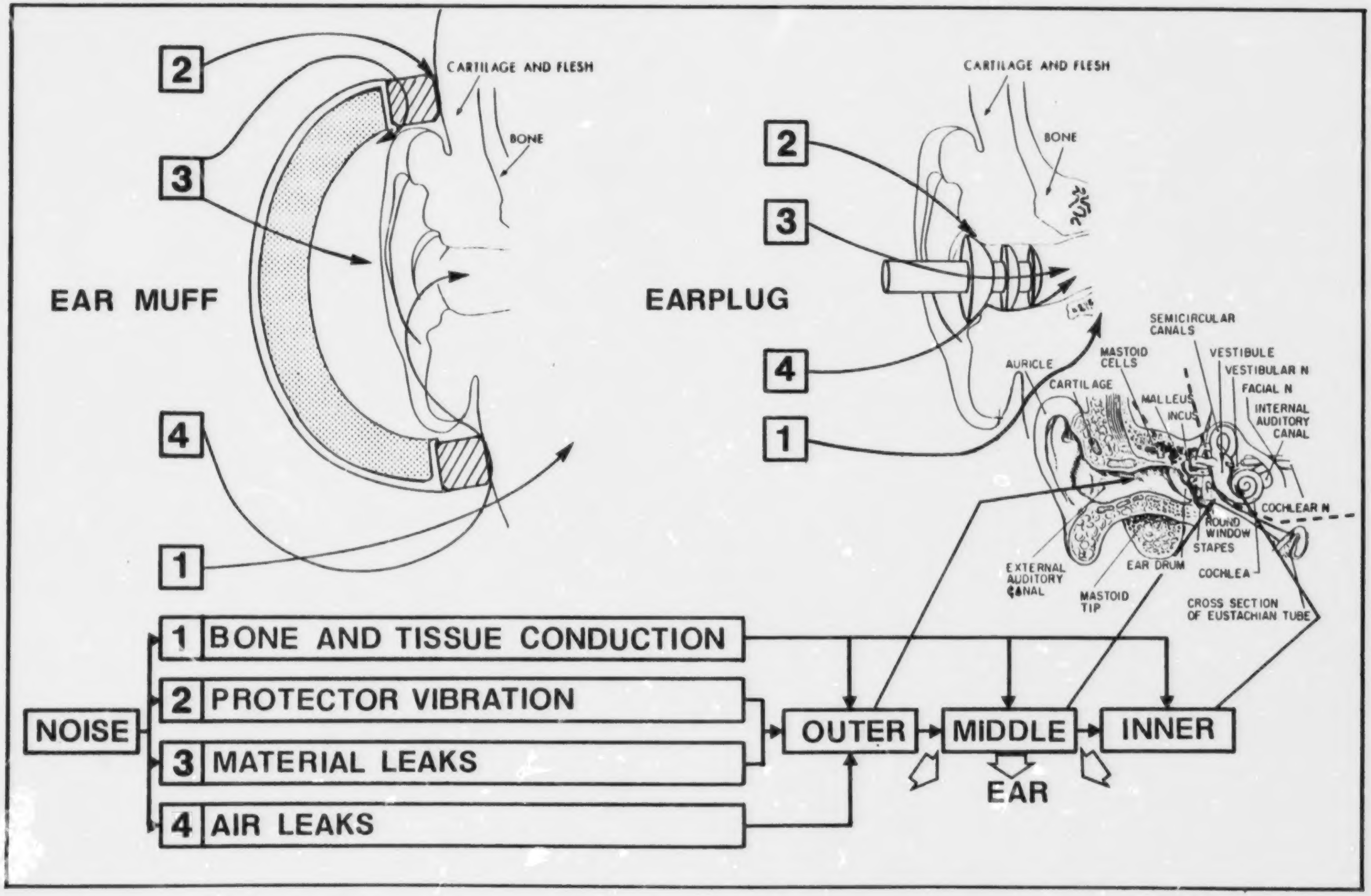
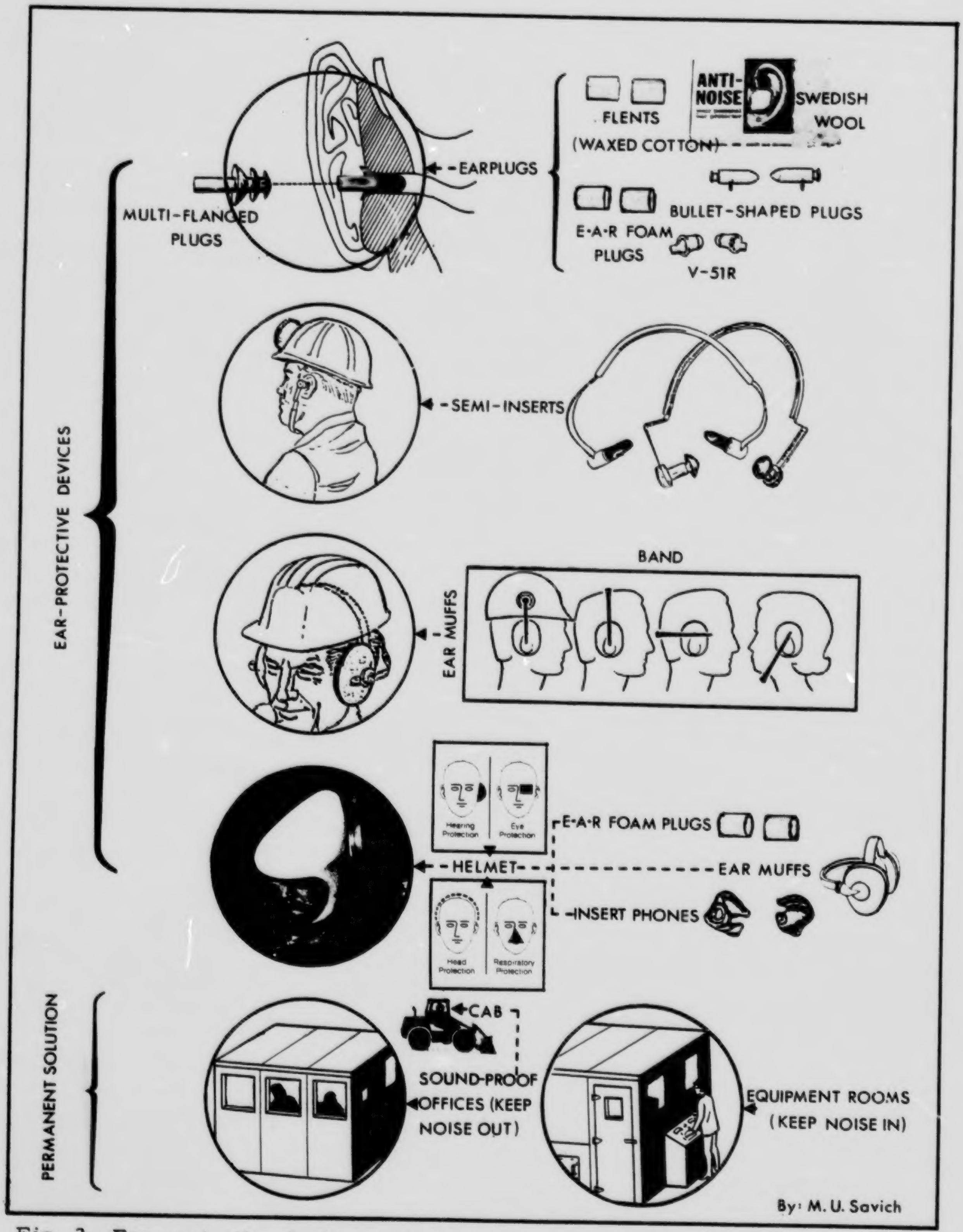

EAR MUFF
EARPLUG
2
3
4
1
CARTILAGE AND FLESH
BONE
AURICLE
CARTILAGE
MASTOID CELLS
MALLEUS
INCUS
SEMICIRCULAR CANALS
VESTIBULE
VESTIBULAR N
FACIAL N
INTERNAL AUDITORY CANAL
COCHLEAR N
ROUND WINDOW
STAPES
COCHLEA
EAR DRUM
EXTERNAL AUDITORY CANAL
MASTOID TIP
CROSS SECTION OF EUSTACHIAN TUBE
NOISE
1 BONE AND TISSUE CONDUCTION
2 PROTECTOR VIBRATION
3 MATERIAL LEAKS
4 AIR LEAKS
OUTER
MIDDLE
INNER
EAR

Fig. 1: Noise transmission paths into the ear when using an ear protector.


EAR-PROTECTIVE DEVICES
MULTI-FLANGED PLUGS
EARPLUGS
FLENTS
(WAXED COTTON)
ANTI-NOISE
SWEDISH WOOL
BULLET-SHAPED PLUGS
E·A·R FOAM PLUGS
V-51R
SEMI-INSERTS
EAR MUFFS
BAND
Hearing Protection
Eye Protection
Head Protection
Respiratory Protection
HELMET
E·A·R FOAM PLUGS
EAR MUFFS
INSERT PHONES
PERMANENT SOLUTION
CAB
SOUND-PROOF OFFICES (KEEP NOISE OUT)
EQUIPMENT ROOMS (KEEP NOISE IN)

By: M. U. Savich

Fig. 2: Ear-protective devices and a permanent solution for hearing protection.

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head; and,

b) fluid-filled cushions similar in size and shape to foam cushions.

c) combination foam and fluid-filled cushions or foam and air-filled cushions.

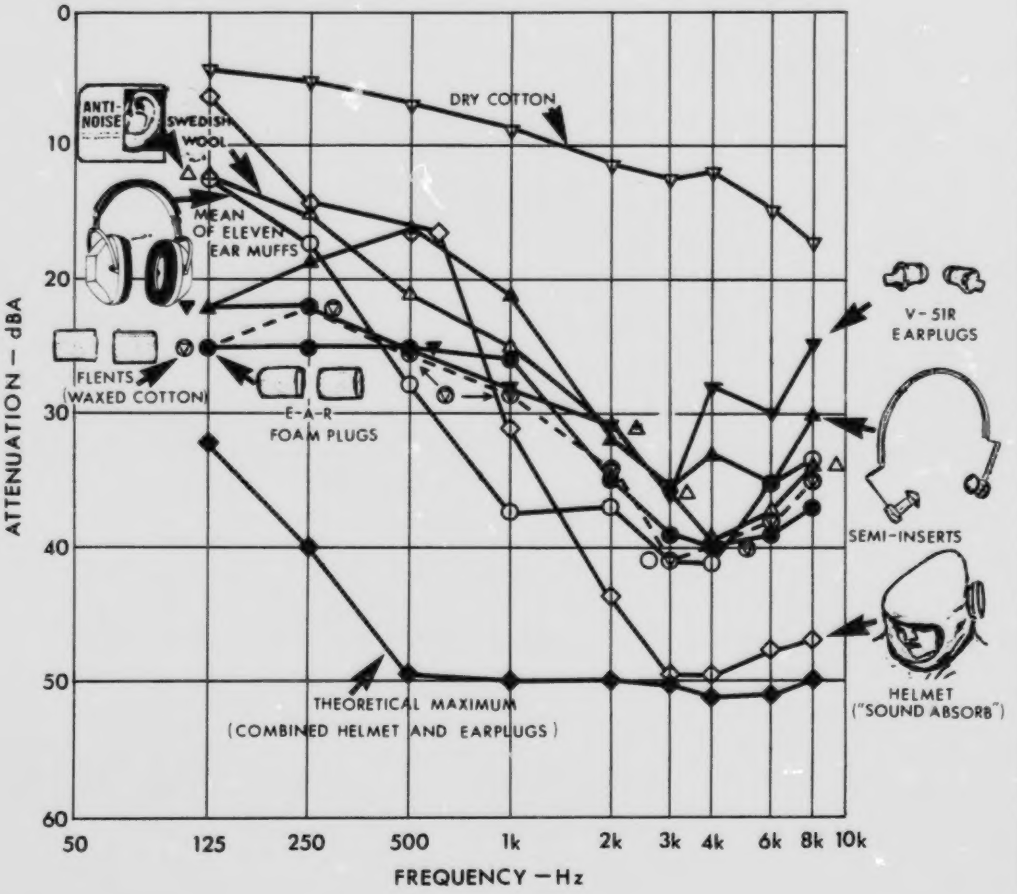
They may be held in place by a headband or a helmet.

4) Helmets that fit over the entire head represent a new development in over-all mine protection: hearing protection, eye protection, head protection and respiratory protection. Noise level is better than 70 dBA at the wearer's ears. The additional attenuation can be improved by ear plugs, ear phones or ear muffs (3). In these systems direct connection of ear muffs to helmets is not advisable because of sound transmission.

Ear protectors must comply with the following basic requirements:

1) To achieve high attenuation of ambient noise. The best ear protectors do not attenuate more than 25 to 30 dB. Attenuation is limited to about 50 dB because noise can by-pass the ear-protective device by pick-up and by conduction through the bone of the head (4). Used by themselves ear plugs are more effective in attenuation at low frequencies than are ear muffs (Fig. 3). Ear plugs and ear muffs can be worn at the same time to provide greater attenuation. The attenuation offered by the combination is less than the sum of the individual attenuations. This phenomenon has not yet been explained. It is believed that a part of the noise enters through the Eustachian tube thus decreasing the ear plug's attenuation.

2) An uncomfortable ear protector becomes intolerable after prolonged



Data from:

- ▽ Dry cotton - McFarland, R. A. and Warren, H. (5).
- ⊗ Flents (waxed cotton) - AIHA* (6).
- △ Swedish wool ("Propp ear plugs") - Bilsom International AB (7).
- ▼ V-51R Ear plugs - MSA** (8).
- ● E-A-R Foam plugs - E-A-R Cabot Corporation (9).
- ▲ Semi-inserts - H. E. Douglass Engineering Sales Co. (10).
- ○ Ear muffs - see Table 2.
- ◇ Helmet ("Sound Absorb") - McFarland, R. A. and Warren, H. (5).
- ◆ Helmet and ear plugs - McFarland, R. A. and Warren, H. (5).

Fig. 3: Attenuation characteristics of ear-protective devices (ANSI+ Z24.22-57).

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* American Industrial Hygiene Association.

** Mine Safety Appliances Company.

+ American National Standards Institute.

wear and has to be removed.

3) Ear protectors may have toxic effects on the skin, thus they must be produced so as to facilitate continual use.

3.1. Technical and Attenuation Data of Ear Muffs

Technical and attenuation data on ear muffs is given in Tables 1 and 2. Cushion areas, cup volumes and weight vary visibly. The lightest ear muff is No. 5, model E, and the heaviest is No. 7, model G because it has fluid filled cushions. Cups are covered by foam on the inside for two reasons: to increase attenuation because uncovered cups permit entry of sound; and to prevent the formation of standing sound waves (the type of waves that are generated in seashells). In addition to the standard foam pad, No. 3 ear muff, model C, contains acoustical fibres (Swedish wool) to provide better sound absorption.

Several attempts have been made in the laboratory to increase attenuation using metal ear muffs, building in a Grason-Stadler earphone socket, adding one or more Helmholtz resonators, or by using soft hollow cushions filled with wax (11). The NRC type ear muff was developed at the National Research Council, Ottawa, by E. A. G. Shaw and G. J. Thiessen (12). This device when properly fitted may be worn for many hours without discomfort (13). Constant technical progress of ear muffs, by all manufacturers, is evident.

3.2. Comfort: One of the Main Requirements of Ear Muffs

The comfort provided by ear muffs depends upon two factors:

1) the ear cushion seal against the head;

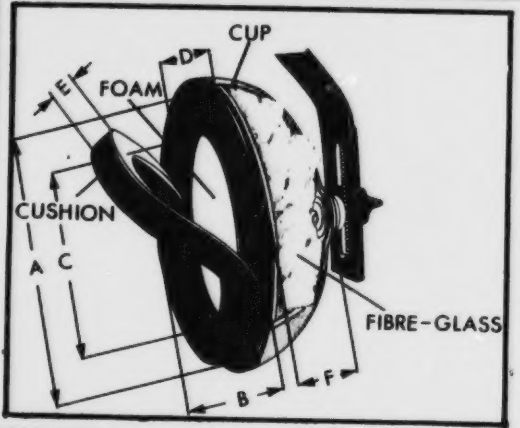


TABLE 1

Technical Data of Ear Muffs Acquired for Testing

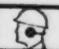
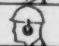
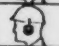
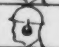
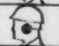
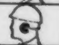
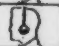
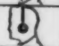
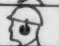
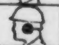
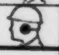
No.	Ear Muff	Filled Cushion	Band	Cross-sectional Dimensions (cm)						Area of Cushion (cm²)	Volume of Cup (cm³)	Weight (g)					Total Weight of Ear Muff (g)
				A	B	C	D	E	F			Cup	Cushion	Foam	Fibre-Glass	Σ wt	
1	A	Foam		9.7	9.7	6.5	4.3	1.1	4.2	48.0	180	49.86	13.67	7.61	-	71.14	185
2	B	Foam and air		9.5	9.5	6.5	4.2	0.8	4.8	40.0	159	73.45	11.44	3.90	-	88.79	284
3	C	Foam		10.7	8.0	6.7	4.0	1.0	3.6	35.6	117	51.13	5.79	0.59	2.46	59.97	188
4	D	Foam		10.5	8.0	6.8	4.1	0.9	3.8	28.5	131	45.30	4.49	1.11	-	50.90	182
5	E	Foam		10.6	8.0	6.8	4.2	1.0	3.8	28.0	131	42.80	4.43	1.27	-	48.50	151
6	F	Foam		9.8	8.3	6.5	3.9	1.0	4.5	43.1	158	63.40	10.47	8.07	-	81.94	291
7	G	Fluid		11.0	8.3	6.3	3.6	0.7	4.4	38.7	167	68.64	56.29	2.90	-	127.83	335
8	H	Foam		11.0	8.3	6.4	3.7	0.8	4.4	42.5	164	57.02	19.87	4.91	-	81.80	274
9	I	Foam		9.4	6.9	6.9	4.6	1.0	4.4	26.7	171	73.94	8.92	3.21	-	86.07	278
10	J	Foam		9.4	6.9	6.9	4.6	0.9	4.4	24.5	171	76.26	9.05	3.34	-	88.65	275
11	K	Foam		11.0	8.2	6.5	4.2	1.0	3.6	42.2	141	52.92	15.92	2.48	-	71.32	295
Σ	Arithmetic Mean of all Ear Muffs			10.24	8.2	6.62	4.13	0.93	4.17	36.16	153.6	59.50	14.58	3.58	2.46	80.12	248
	Std. Dev.			0.68	0.86	0.21	0.32	0.12	0.4	7.98	20.4	12.16	14.63	2.46	-	29.25	60.5

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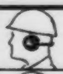
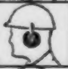
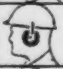
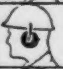
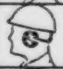
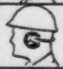
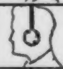
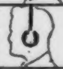
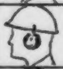
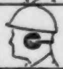
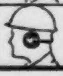
TABLE 2

Attenuation Characteristics of Ear Muffs Acquired for Testing

No.	Ear Muff	Band	Attenuation (dB)*									
			Characteristic	Frequency in Hertz								
				125	250	500	1k	2k	3k	4k	6k	8k
1	A		Measured	9.7	16.1	24.9	33.9	34.1	36.0	41.0	33.8	31.5
			Std. Dev.	3.2	2.5	2,8	5.1	2.9	5.6	5.7	6.6	5.9
2	B		Measured	5	13	22	31	31	41	36	28	21
			Std. Dev.	-	-	-	-	-	-	-	-	-
3	C		Measured	10	16	30	34	37	41	45	39	34
			Std. Dev.	-	-	-	-	-	-	-	-	-
4	D		Measured	11.5	16.5	26.5	36.5	38	38.5	44.5	39.5	-
			Std. Dev.	-	-	-	-	-	-	-	-	-
5	E		Measured	13.4	17.3	28.6	41.8	40.7	45.2	42.7	32.6	29.3
			Std. Dev.	3.3	3.9	3.0	3.4	5.6	4.6	5.3	4.1	4.7
6	F		Measured	17	18	29	36	38	44	44	43	43
			Std. Dev.	2.6	2.6	3.1	3.2	4.1	7.2	4.6	4.7	5.7
7	G		Measured	18	23	33	44	44	47	45	42	39
			Std. Dev.	-	-	-	-	-	-	-	-	-
8	H		Measured	18	23	33	44	44	47	45	42	39
			Std. Dev.	-	-	-	-	-	-	-	-	-
9	I		Measured	12	17	30	35	35	36	37	32	30
			Std. Dev.	2.5	3.0	4.6	5.6	4.5	4.3	4.2	4.1	2.9
10	J		Measured	10	17	28	37	36	44	39	32	30
			Std. Dev.	2.0	2.6	4.3	5.4	4.5	5.6	3.8	5.4	4.9
11	K		Measured	15	17	26	43	36	38	38	33	34
			Std. Dev.	5.2	3.9	8.8	3.6	4.9	6.6	6.8	1.3	5.3
Σ	Arithmetic Mean of all Ear Muffs			12.16	17.09	27.8	37.22	36.98	41.07	41.22	35.49	33.53
	Std. Dev.			3.86	2.47	3.09	4.31	3.58	3.9	3.49	5.0	7.36

* Attenuation characteristic measured in accordance with American National Standard Specification Z.24.22-1957 (from Factory Data).

2) the muff design.

3.2.1. Ear Cushion Seal Against the Head

The pressure of ear cushion seals against the head is a direct consequence of the clamping force, adjustment, softness and weight.

Clamping force (Head force): The clamping force is the force exerted by an ear muff on the skin and it is the most important element of discomfort. Generally, as the clamping force increases, the attenuation offered by an ear muff also increases. If the pressure is high for a long period of time, the pain may become intolerable. The pressure exerted by ear muffs varies directly with the force applied by their supporting means. The clamping force against the sides of the head varies between 500 and 1000 g wt (14). Pressure limits have not yet been specified for ear muffs, however, pressure against the head is an important aspect. Greatest pressure is needed when the muffs are first put on to ensure a correct fit. Once a good seal has been obtained, the pressure can be decreased. A certain amount of pressure on the skin is necessary to hold the ear muffs in the proper place so that good attenuation is obtained. The contact area between the ear protector and the skin must be set so as not to hinder blood circulation. The clamping force varies and depends on the bizygomatic diameter of the head.

For the measurement of clamping (head band) force two pieces of apparatus were constructed in the Elliot Lake Laboratory. One is for the measurement of clamping forces of ear muffs with a head band, (Appendix 1), and the other is for the measurement of clamping forces of ear muffs mounted on helmets (Appendix 2). The second apparatus measures the asymmetry of clamping forces with a helmet.

Adjustment: Ear muff adjustment obviously depends upon the shape and dimensions of a worker's head. To fulfil the criterion of a tight fit, the muffs should have the capability of moving the support up and down so as to be parallel with the wearer's ears. To make allowances for each person's unique head shape, they should also be rotational on a pivot point (Fig. 4).

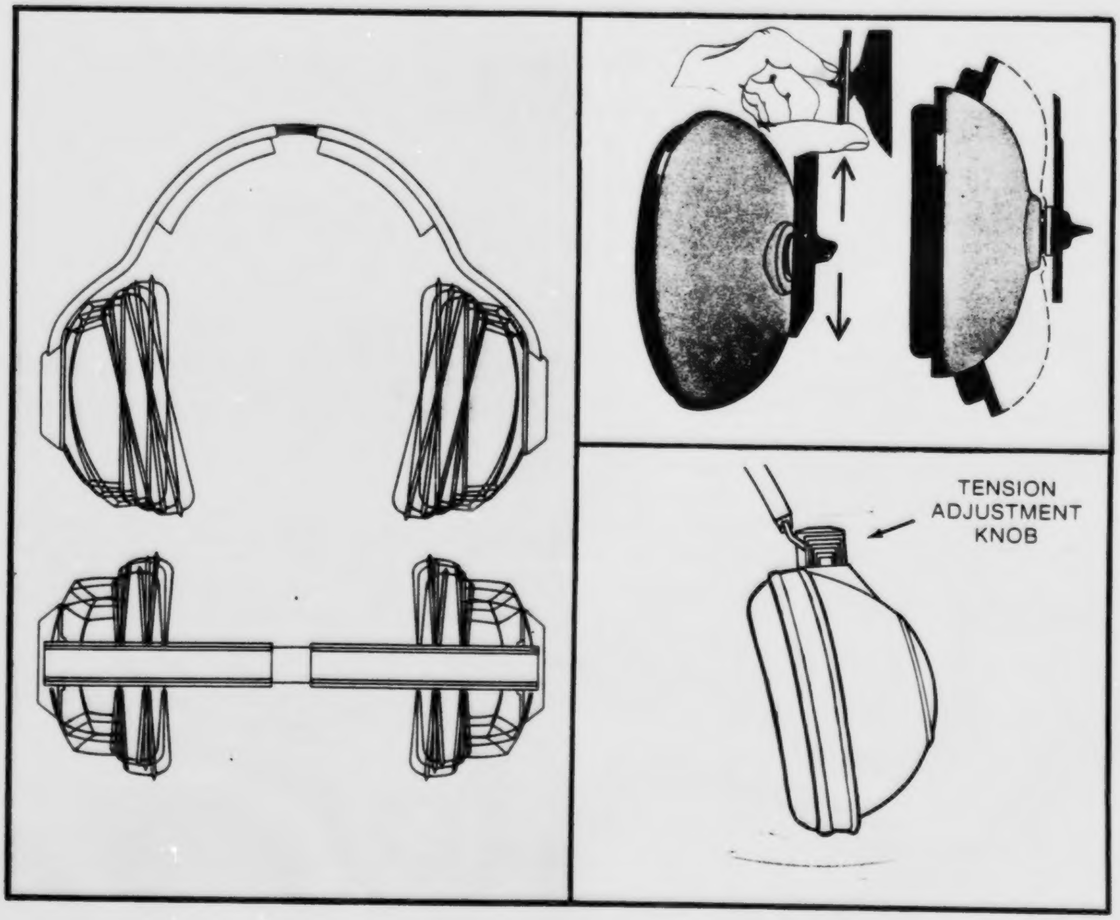


Fig. 4: The muffs should assume the correct angle to the head (15) (16) (17).

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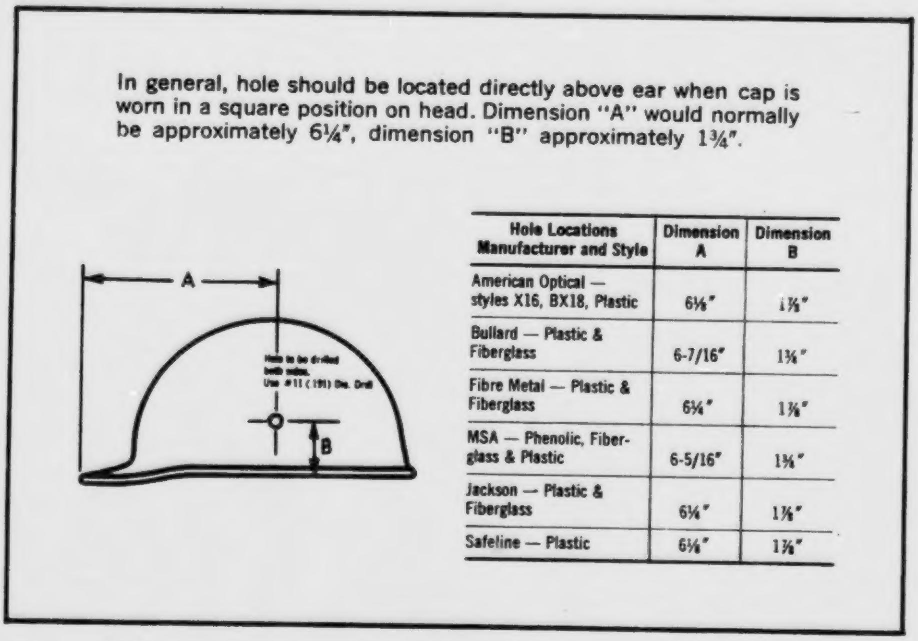
An effective seal inside the cup prevents acoustical leakage around the bearing surface.

A bad connection between the helmets and the cups hinders clamping force and comfort. Poor mounting of asymmetrical ear muffs is caused by two things; a shortage of manufacturer's data for hole locations on helmets and the poor mounting of ear muffs on helmets in mines. Only American Optical has holes located in different places for different helmets (Fig. 5)(18). Some of the biggest manufacturers of ear muffs produce helmets and stipulate the joint sale of ear muffs and helmets.



In general, hole should be located directly above ear when cap is worn in a square position on head. Dimension "A" would normally be approximately 6¼", dimension "B" approximately 1¾".

Hole Locations Manufacturer and Style	Dimension A	Dimension B
American Optical — styles X16, BX18, Plastic	6⅛"	1⅞"
Bullard — Plastic & Fiberglass	6-7/16"	1¾"
Fibre Metal — Plastic & Fiberglass	6¼"	1⅞"
MSA — Phenolic, Fiberglass & Plastic	6-5/16"	1¾"
Jackson — Plastic & Fiberglass	6¼"	1⅞"
Safeline — Plastic	6⅛"	1⅞"

Fig. 5: Hole locations in helmets (18).

The best solution is to use a support strap in conjunction with a safety helmet (Fig. 6). The strap provides support for all ear muff type protectors when worn behind the head (back-band with strap). This head-

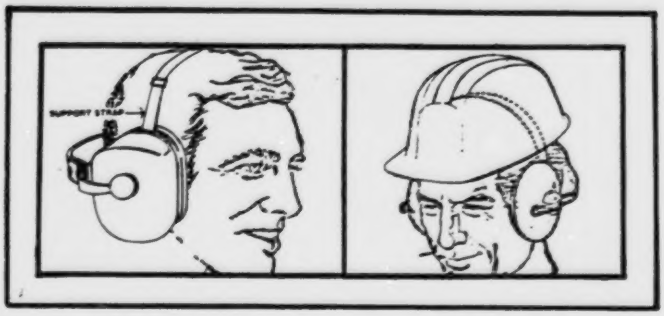


Fig. 6: Support strap: adjustable, lightweight, easily adaptable and comfortable (19) (20).

strap is adjustable over the head to avoid discomfort caused by the pull of gravity on the ear cups. It also holds the ear cups in position over the ears. Helmets need not be drilled or tampered with. Loss of attenuation is minimal.

Softness: Softness is a prime consideration for ear cushions. Apart from the vital aspect of comfort, an effective noise seal depends upon the cushion being soft enough to assume the contours of the head and to fit snugly around the frames of glasses or eyeglass adapters. The comfort collar fits over the ear cushion and provides an agreeable, and hygienic contact surface (Fig. 7).

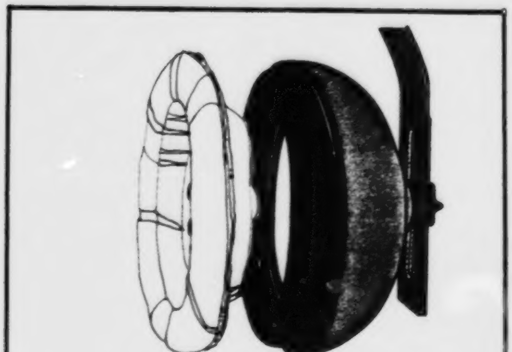
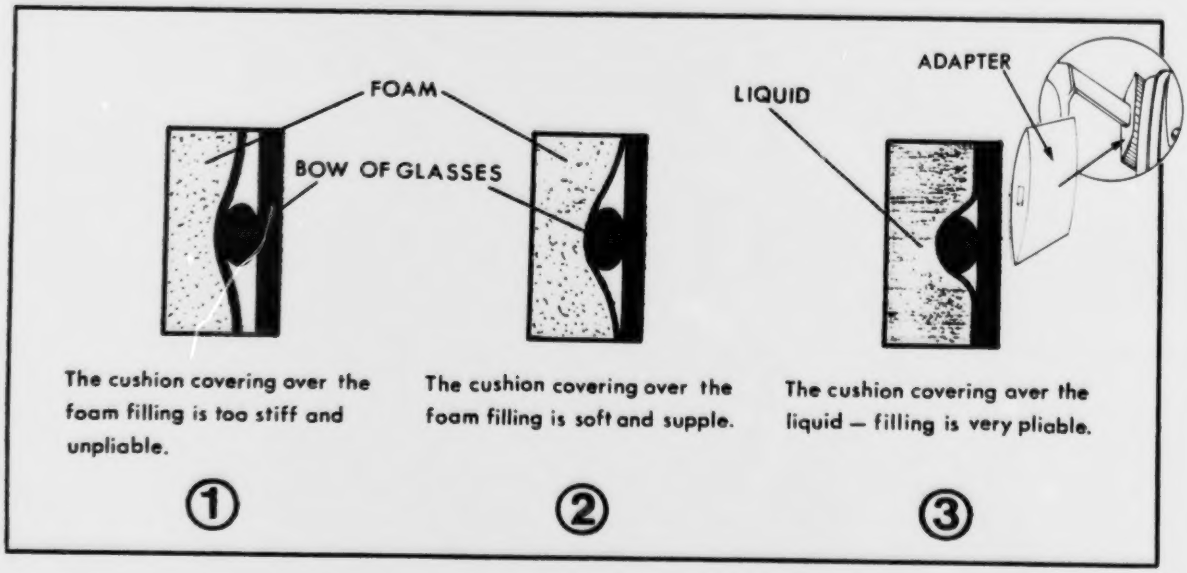


Fig. 7: The comfort collar (16).

6766.

The comfort collar protects ear cushions from becoming soiled, thus extending their useful life. This is an important economic aspect. Made of soft paper tissue, it absorbs perspiration around the ear and makes ear muffs comfortable to wear (16).

New materials for cushion seals perform the function of adapters. The No. 3 ear muff, model C, has foam filled cushions with covering material of soft, supple plastic film (Fig. 8). Some ear cups have special cushions with replaceable snap in/out foam over a liquid sealing ring to afford even pressure without gaps, even when wearing eye glasses.



The cushion covering over the foam filling is too stiff and unpliable.

①

The cushion covering over the foam filling is soft and supple.

②

The cushion covering over the liquid — filling is very pliable.

③

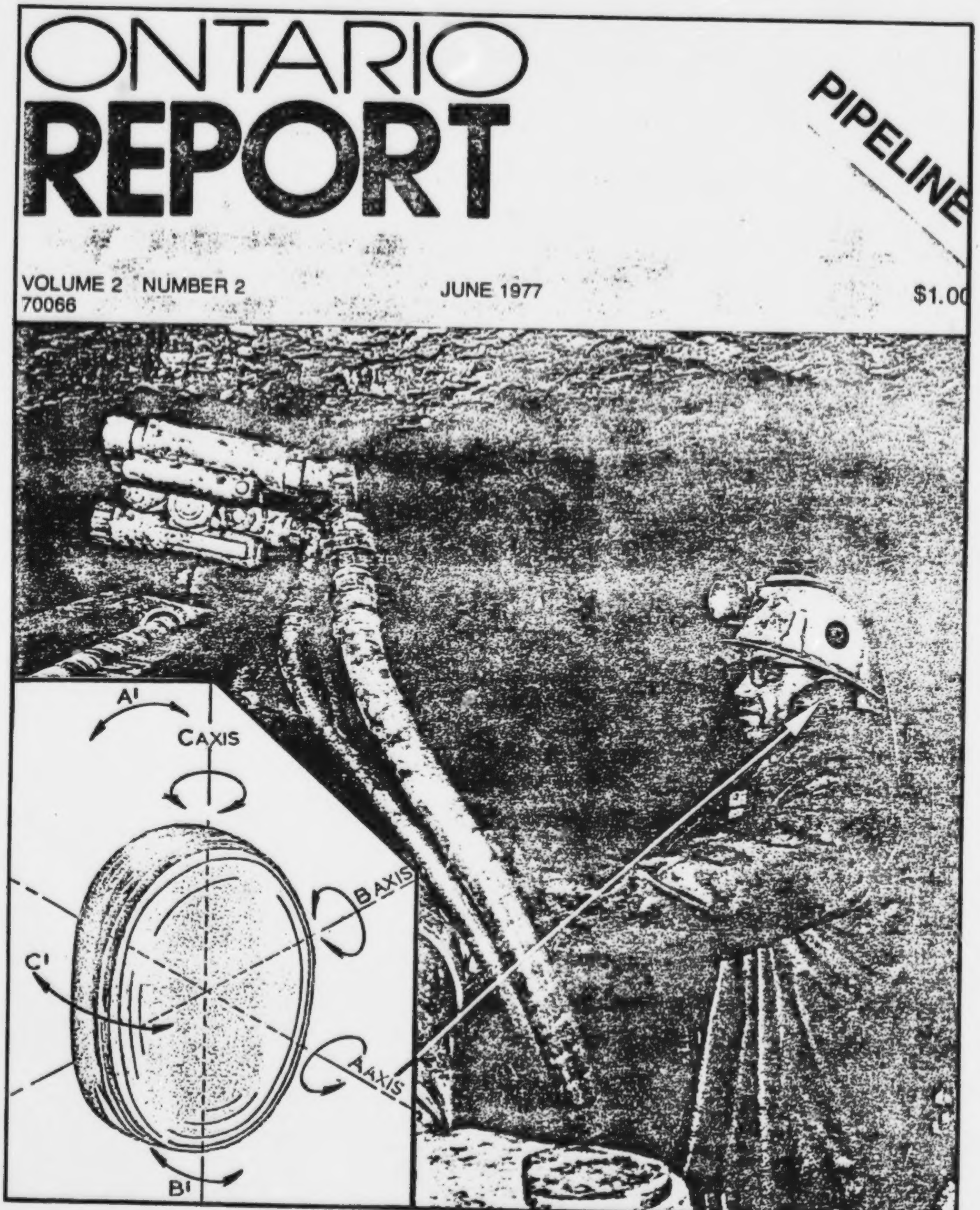
Fig. 8: Material for cushion seals.

Weight: The weight of ear muffs affects comfort greatly because the force of gravity adds to the irritants already present. The total weight of a pair of muffs varies between 151 g and 335 g (Table 1). Their lightness provides comfort even for one full shift of wearing. Heavy muffs become a bother and they increase fatigue for short periods of use. Too low a weight is not good since sound attenuation becomes lower. Lightweight ear muffs maximize the wearer's overall comfort. For comfort, the weight of an ear muff must be limited to approximately 200 grams (21).

3.2.2. The Design of Ear Muffs

Designing is an important requirement, especially for things that are worn. Two main factors in the design of ear muffs are: ease of handling, and choice of materials. Ear muffs should be functional and easily handled. Two properties facilitate ease of handling: mechanical simplicity and symmetry (2). Basic principles of mechanical simplicity demand that ear muffs be constructed so simply that instructions for their use are not necessary. The supporting systems, and their muff attachments, are usually so weak that they become bent out of shape. Steel wire supports can be deformed, thus the effect of attenuation is significantly reduced. The fiberglass reinforcement gives the support outstanding flexibility, strength, and resistance to deformation and corrosion. In particular, the connection between the ear muff and the support is very important. If the ear muff is easily rotated around the A-axis, a user is more likely to wear it incorrectly, thus leaving a part of his outer ear uncovered. Such cases are often seen in practice (Fig. 9).

Ear muffs have different degrees of symmetry. Usually ear muffs are symmetrical, except those that are mounted on a helmet. Asymmetrical ear muffs mounted on helmets are a major source of poor attenuation.


ONTARIO
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PIPELINE
VOLUME 2 NUMBER 2
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JUNE 1977
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A'
C AXIS
B AXIS
C'
A AXIS
B'

Fig. 9: The design of this ear muff is not good because it is permitted to rotate around the A-axis. As a direct consequence of this, a part of the outer ear is left uncovered.

6766.

4. TESTS OF COMFORT

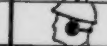
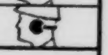
Ear muffs must be sufficiently comfortable to be worn for long periods of time, perhaps up to 8 or 10 hours a day. The comfort of ear muffs can be evaluated quantitatively, however, such a test has yet to be devised (2). Simple qualitative inquiries were performed in the Elliot Lake Laboratory to determine whether ear muffs are comfortable.

Male members of the Elliot Lake Laboratory, and several guests, took part in the tests. Women were eliminated from the tests because there is no significant participation by them in mining industries (22). Qualitative evaluation was divided into three categories: 1) satisfactory; 2) good; and 3) very good. The experiment was designed so that the differences among age (rows) and qualitative evaluation (columns) represented a major source of variation. Such an arrangement is known as a Latin square (23). We used the method of industrial elimination in the parallel entries. This method is widely used in the selection of industrial products for the elimination of judges whose performance is erratic. A gray No. 7 ear muff, model G, with fluid filled cushions, and a yellow No. 8 ear muff, model H, with sponge filled cushions, were used. Comfort provided by these two ear muffs was relatively equal.

The summary of findings, relating data obtained from 27 subjects, is presented in Table 3. The results of an F-test confirmed a significant difference between muffs. By industrial elimination (muffs No. 7 and No. 8) we can determine which subjects are reliable and which ones are not. Ear muff No. 2 with foam and air filled cushions was chosen as the most

TABLE 3

Comfort Test of Ear Muffs Before Industrial Elimination

NO.	NUMBER OF SUBJECT	1	2	3	4	5	6	7	8*	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Σx²	BAND
	EAR MUFF / AGE	19	24	28	28	29	29	30	30	30	30	37	38	38	40	40	42	42	46	46	47	49	52	52	55	57	59	60		
1	A	⬙	◆	◆	⬙	⬙	◆	⬙	◆	◆	◆	◆	⬙	⬙	⬙	◆	◆	◆	⬙	◆	◆	⬙	⬙	⬙	◆	⬙	◇	⬙	74	
2	B	⬙	⬙	⬙	◇	◇	⬙	⬙	⬙	⬙	◇	◆	⬙	◆	⬙	◇	◇	⬙	⬙	⬙	◆	◆	⬙	⬙	◇	⬙	⬙	◇	⑬¹ 131	
3	C	◆	◆	⬙	◆	⬙	⬙	◆	◆	◇	⬙	◆	◆	◆	⬙	◆	⬙	⬙	⬙	⬙	⬙	◆	◆	◆	◆	◆	◇	⬙	76	
4	D	◆	◇	◆	⬙	◇	◆	⬙	◆	◆	⬙	◆	◆	◆	◆	⬙	◇	◆	◆	◆	◆	⬙	⬙	◆	◇	⬙	⬙	◆	88	
5	E	⬙	◆	◆	⬙	◇	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	⬙	◆	⬙	⬙	◆	◆	50	
6	F	◇	◇	⬙	◇	◇	⬙	◆	◆	◆	◆	◆	◆	⬙	◆	⬙	⬙	◆	⬙	◆	⬙	◆	◇	◆	⬙	⬙	⬙	⬙	100	
7	G	◇	◆	⬙	◇	◆	◆	⬙	◇	◇	◆	⬙	◆	⬙	◆	◆	⬙	⬙	◇	⬙	◆	⬙	◇	⬙	◇	⬙	⬙	⬙	119	
8	H	⬙	◆	◆	⬙	◆	⬙	◇	◆	⬙	◆	⬙	⬙	◆	⬙	◆	⬙	⬙	⬙	⬙	⬙	⬙	◇	⬙	◇	⬙	⬙	⬙	102	
9	I	⬙	◇	◆	◇	◆	⬙	⬙	◆	◇	◆	◆	⬙	◆	⬙	⬙	◇	⬙	⬙	⬙	⬙	◆	⬙	⬙	◇	⬙	◇	⬙	117	
10	J	⬙	⬙	⬙	◆	◇	◆	◆	⬙	⬙	◆	⬙	⬙	⬙	⬙	◆	⬙	◆	⬙	⬙	⬙	⬙	⬙	◇	◇	◆	⬙	◆	99	
11	K	◇	⬙	⬙	⬙	◆	⬙	◇	◆	◇	◆	⬙	◇	⬙	◆	◆	⬙	◆	⬙	◇	⬙	⬙	◇	⬙	◆	⬙	◇	⬙	122	
	Σx²	53	44	29	58	57	29	42	25	52	25	23	34	26	29	28	53	26	43	37	29	29	61	37	65	38	66	40	1078	

NOTE: Evaluation
- ◆ Satisfactory (1)
- ⬙ Good (2)
- ◇ Very Good (3)

* Subject No. 8 had extremely opposite judgement of ear muffs 7 and 8 and must be eliminated in further calculations.

(131) Maximum

{ Industrial elimination }

ANOVA 12:46 06/09/77 THURSDAY TO1

N-WAY ANALYSIS OF VARIANCE

LATIN SQUARE

FACTOR	LEVEL
1	27 - SUBJECTS
2	11 - MUFFS

LINE NO.	VARIANCE * COMPONENT	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES
1	CMP(1)	29.11784	26	1.11992
2	CMP(2)	14.50505	10	1.45050
3	CMP(12)	104.58580	260	0.40225
	TOTAL	148.20870	296	

* E. G., CMP(12) MEANS COMPONENT OF FACTORS 1 AND 2

GRAND MEAN 1.78451

LINE FOR (A), PLEASE ? 1
LINE FOR (B), PLEASE ? 3

F-RATIO = 2.78411 (D.F. = 26, 260)

LINE FOR (A), PLEASE ? 2
LINE FOR (B), PLEASE ? 3

F-RATIO = 3.60595 (D.F. = 10, 260)

Results of F Test			
	Factor	Distribution	
		5% Level of Significance	1% Level of Significance
Muffs	3.61	1.83	2.32
Subjects	2.79	1.50	1.76

THE RESULTS SHOW A SIGNIFICANT DIFFERENCE BETWEEN MUFFS. BY INDUSTRIAL ELIMINATION (MUFFS 7 AND 8) WE CAN DETERMINE THE SUBJECTS THAT ARE RELIABLE AND THOSE THAT ARE NOT.

EAR MUFF NO. 2 WAS CHOSEN AS THE MOST COMFORTABLE OVERALL.

comfortable of all. The data obtained from fourteen reliable subjects (mean age is 45.5 ± 3.09 years) show a significant difference between muffs (Table 4). Again, ear muff No. 2 was chosen as the most comfortable of all. From Table 5, no conclusions can be drawn since, by industrial elimination, the subjects (mean age is 34.17 ± 2.37 years) were shown to be poor judges. In the analysis, more value was placed on ear muffs with larger cushion areas (Table 1).

5. BIZYGOMATIC DIAMETER SURVEY

The variety of size, shape, and contour of the human head poses a difficult problem to the manufacturer of ear muff protective devices. The major reason for making the bizygomatic diameter survey was to evaluate the clamping force required in ear muff design.

A measurement of maximum distance between the bony structures (zygomatic arches) forward of the ears has been carried out on 27 men in the Elliot Lake Laboratory (Fig. 10).

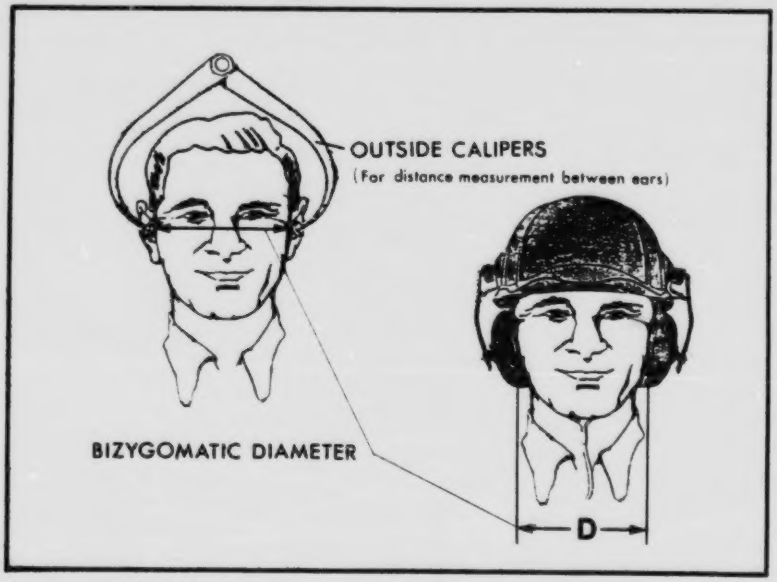
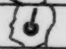
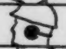
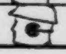


Fig. 10: Bizygomatic diameter measurement with calipers.

TABLE 4

Comfort Test of Ear Muffs Using Industrial Elimination

NO.	NUMBER OF SUBJECT	2	5	10	15	16	17	19	21	22	23	24	25	26	27	Σx^2	← 14 SUBJECTS BAND	
	EAR MUFF / AGE	24	29	30	40	42	42	46	49	52	52	55	57	59	60			
1	A	◆	⬙	◆	◆	◆	◆	◆	⬙	⬙	⬙	◆	⬙	◇	⬙	40		
2	B	⬙	◇	◇	◇	◇	⬙	⬙	◆	⬙	⬙	◇	⬙	⬙	◇	(83)		
3	C	◆	⬙	⬙	◆	⬙	⬙	⬙	◆	◆	◆	◆	◆	◇	⬙	40		
4	D	◇	◇	⬙	⬙	◇	◆	◆	⬙	◆	⬙	◇	⬙	◇	◆	69		
5	E	◆	◇	◆	◆	◆	◆	◆	◆	◆	⬙	⬙	⬙	◆	◆	31		
6	F	◇	◇	◆	⬙	⬙	◆	◆	◆	◆	◇	⬙	⬙	⬙	⬙	56		
7	G	◆	◆	◆	◆	⬙	⬙	⬙	⬙	⬙	◇	◇	⬙	⬙	⬙	54		
☒	H	◆	◆	◆	◆	⬙	⬙	⬙	⬙	⬙	◇	◇	⬙	⬙	⬙	54		
9	I	◇	◆	◆	⬙	◇	⬙	⬙	◆	⬙	⬙	◇	⬙	◇	⬙	67		
10	J	⬙	◇	◆	◆	⬙	◆	⬙	⬙	◇	⬙	◇	◆	⬙	◆	56		
11	K	⬙	◆	◆	◆	⬙	◆	◇	⬙	⬙	◇	◆	⬙	◇	⬙	56		
	Σx^2	43	56	24	27	49	22	33	25	33	52	56	34	62	36	562		

NOTE: Evaluation
- ◆ Satisfactory (1)
- ⬙ Good (2)
- ◇ Very Good (3)

(83) Maximum

{Industrial elimination}

```
ANOVA      11:05    06/09/77    THURSDAY    TO1

N-WAY ANALYSIS OF VARIANCE

FACTOR   LEVEL
  1       14 - SUBJECTS
  2       10 - MUFFS

LINE   VARIANCE *     SUM OF      DEGREES OF     MEAN
NO.    COMPONENT      SQUARES     FREEDOM        SQUARES

 1     CMP(    1)     16.94286        13         1.30330
 2     CMP(    2)     10.54286         9         1.17143
 3     CMP(   12)     49.05713       117         0.41929

          TOTAL       79.54283       139

* E.G., CMP(12) MEANS COMPONENT OF FACTORS 1 AND 2

GRAND MEAN        1.84286
```

LATIN SQUARE

Results of F Test

	Factor	Distribution	
		5% Level of Significance	1% Level of Significance
Muffs	2.79	1.96	2.56
Subjects	3.11	1.80	2.26

RESULTS FROM RELIABLE SUBJECTS SHOW A SIGNIFICANT DIFFERENCE BETWEEN MUFFS. EAR MUFF NO. 2 WAS CHOSEN AS THE MOST COMFORTABLE OVER ALL.

```
LINE FOR (A), PLEASE ?
LINE FOR (B), PLEASE ? 3

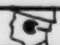
F-RATIO  =  3.1083  (D.F.  =  13, 117)

LINE FOR (A), PLEASE ? 1
LINE FOR (B), PLEASE ? 3

F-RATIO  =  2.7938  (D.F.  =  9, 117)
```

TABLE 5

Comfort Test of Ear Muffs After Industrial Elimination

NO.	NUMBER OF SUBJECT	1	3	4	6	7	9	11	12	13	14	18	20	Σx^2	← 12 SUBJECTS BAND
	EAR MUFF / AGE	19	28	28	29	30	30	37	38	38	40	46	47		
1	A	⬙	◆	⬙	◆	⬙	◆	◆	⬙	⬙	⬙	⬙	◆	33	
2	B	⬙	⬙	◇	⬙	⬙	⬙	◆	⬙	◆	⬙	⬙	◆	44	
3	C	◆	⬙	◆	⬙	◆	◇	◆	◆	◆	⬙	⬙	⬙	35	
4	D	◆	◆	⬙	◆	⬙	◆	◆	◆	◆	◆	◆	◆	18	
5	E	⬙	◆	⬙	◆	◆	◆	◆	◆	◆	◆	◆	◆	18	
6	F	◇	⬙	◇	⬙	◆	◆	◆	◆	⬙	◆	⬙	⬙	43	
7	G	◇	⬙	◇	◆	⬙	◇	⬙	◆	⬙	◆	◇	◆	56	
8	H	⬙	◆	⬙	⬙	◇	⬙	⬙	⬙	◆	⬙	⬙	⬙	47	
9	I	⬙	◆	◇	⬙	⬙	◇	◆	⬙	◆	⬙	⬙	⬙	49	
10	J	⬙	⬙	◆	◆	◆	⬙	⬙	⬙	⬙	⬙	⬙	⬙	39	
11	K	◇	⬙	⬙	⬙	◇	◇	⬙	◇	⬙	◆	⬙	⬙	65	
	Σx^2	53	29	58	29	42	52	23	34	26	29	43	29	447	

NOTE: Evaluation
- ◆ Satisfactory (1)
- ⬙ Good (2)
- ◇ Very Good (3)

{ Industrial elimination }

```
ANOVA          13:08      06/09/77      THURSDAY      TO1

N-WAY ANALYSIS OF VARIANCE

FACTOR   LEVEL
  1        12 - SUBJECTS
  2        11 - MUFFS

LINE    VARIANCE *     SUM OF     DEGREES OF      MEAN
NO.     COMPONENT      SQUARES     FREEDOM       SQUARES

 1      CMP(     1)    8.81061        11         0.80096
 2      CMP(     2)   13.21212        10         1.32121
 3      CMP(    12)   34.60605       110         0.31460

          TOTAL       56.62877       131

* E.G., CMP(12) MEANS COMPONENT OF FACTORS 1 AND 2

GRAND MEAN        1.7197
```

LATIN SQUARE

NO CONCLUSIONS CAN BE DRAWN SINCE SUBJECTS WERE SHOWN TO BE POOR JUDGES BY INDUSTRIAL ELIMINATION.

```
LINE FOR (A), PLEASE? 1
LINE FOR (B), PLEASE? 3

F-RATIO = 2.54597 (D.F. = 11, 110)


LINE FOR (A), PLEASE? 2
LINE FOR (B), PLEASE? 3

F-RATIO = 4.19965 (D.F. = 12, 110)
```

The arms of the calipers were pressed against the bone just forward of the ears. The same calipers were used for measurement in mines.

Statistical analysis of the samples showed that small, but significant differences existed between origin groups (Table 6). The population in the Elliot Lake Laboratory is basically of European origin and is largely made up of people originating from the United Kingdom and Ireland. Subjects were grouped as to origin in the United Kingdom, Con. Europe, Asia, these regions being those represented by the population. The number of people of non-Caucasian origin is very large, ~26 per cent of the population.

In the literature, the volume of bizygomatic diameter data which has been published of Caucasian ethnic origin is relatively small. Comparison of results from Table 6, with other surveys from the literature from Table 7 showed minor differences of no practical importance.

Table 6 and Table 7 show a breakdown of the survey data into United Kingdom origin (Australian, U.S. Air Personnel, U.S. Army) versus Continental European groups. Results from Table 6, showed differences between United Kingdom origin (14.17 ± 0.13) and Continental European groups (14.74 ± 0.28). Also, from Table 7 can be seen similar relations between Australian and United Kingdom-born versus other Foreign-born, and the U.S. Air and Army personnel versus NATO Forces. It would appear that the bizygomatic diameters of United Kingdom origin population are slightly smaller, differences being significant between these two groups. The Asian Group is too small for statistical comparison. Bizygomatic

TABLE 6

Bizygomatic Diameter Surveys in Elliot Lake Laboratory

No.	Population	No. of persons	Means	
			D (cm)	Age (years)
1	Caucasian	20	14.47 ± 0.17	38.70 ± 2.55
2	Non-Caucasian	7	14.13 ± 0.26	43.29 ± 4.43
3	Canadian+	16	14.43 ± 0.16	38.94 ± 3.07
4	Non-Canadian+	11	14.23 ± 0.26	41.27 ± 3.18
5	U.K.++	13	14.17 ± 0.13	37.38 ± 2.90
6	Cont. Europe++	10	14.17 ± 0.28	45.20 ± 4.13
7	Slavic++	5	15.05 ± 0.50	44.80 ± 4.55
8	Asia+++	7	14.13 ± 0.26	43.29 ± 4.43
9	Age 19 - 39	13	14.05 ± 0.15	30.00 ± 1.48
10	Age 40 - 60	14	14.44 ± 0.19	49.07 ± 1.85
Σ	Canadian	27	14.35 ± 0.14	39.89 ± 2.21

+ 16 Canadian-born versus 11 non-Canadian-born.

++ U.K. origin, Cont. Europe origin, Slavic origin in Cont. Europe.

+++ Including Hungary and Finland.

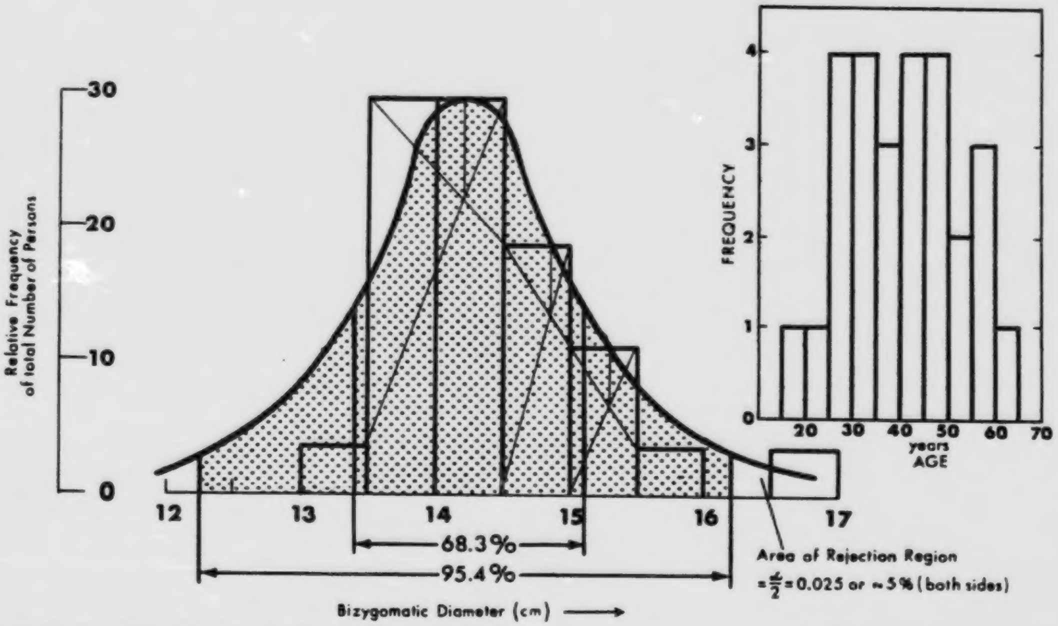


TABLE 7

Bizygomatic Size Surveys from Literature

Mean and Standard Deviations of Australian-Born Versus Non-Australian-Born Subgroups (24)

Parameter	Australian-Born	Non-Australian-Born	U.K.-Born	Other Foreign-born
No. of persons	230	105	53	52
Bizygomatic diameter (cm)	14.04 ± 0.58	14.27 ± 0.6 ($p<0.01$)	14.06 ± 0.61*	14.48 ± 0.51 ($p<0.001$)

* Not significant

Mean and Standard Deviation of Other Foreign-Born Subgroups

Parameter	Northern and Central Europe	Southern Europe	Asia	New Zealand
No. of persons	24	13	7	8
Bizygomatic diameter (cm)	14.58 ± 0.55	14.53 ± 0.48	14.26 ± 0.52	14.30 ± 0.35

Bizygomatic Size Surveys, Mean Figures (25) (26) (27)

Parameter	U.S. Air Personnel (1950)	U.S. Army (1945)	NATO Forces (1963)			Australians (1966)	Romanians (1967)
			Turks	Greeks	Italians		
No. of persons	4000	3075 (white) 32 (negro)	915	1084	1358	335	Approx. 3000
Bizygomatic diameter (cm)	14.08	13.98	14.22	14.18	14.31	14.11	13.76

diameter surveys indicate that differences in ethnic origin may be sufficient to affect clamping force in some instances.

The standard ANSI S3.19-1974 recommended for the measurement of clamping force used hearing protectors separated to a distance of 14.35 cm between ear cups (medium head width) (Appendix 3).

6. CONCLUSIONS

The most important function of an ear muff is that it will attenuate noise whilst providing a comfortable fit. Manufacturers claim that ear muffs are shaped to fit all ears comfortably; this is not always the case. Some of the main problems encountered in ear muffs are caused by the ear cushion seal against the head and their functional design. In comfort tests it was demonstrated that ear muffs with large area of cushions were favoured (Table 1).

It can be concluded from an examination of the comparative data in bizygomatic diameter surveys that there is a wide range of head size in any single population. However, commercial ear muffs examined will fit this range with corresponding changes in the clamping force.

7. ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Mines Accident Prevention Association of Ontario for providing a selection of ear muffs for this project. He is also indebted to E.D. Dainty, Project Leader, CEAL, Ottawa; and to Dr. R. Tervo, Manager, G. Knight, research scientist, and Dr. N.K. Davé, research fellow, Elliot Lake Laboratory, who were helpful in many ways. Grateful acknowledgement is given to A. Webster who transcribed and completed the tables. He acknowledges the contribution of W. Stefanich and W. Zawadski for their assistance in the Laboratory work.

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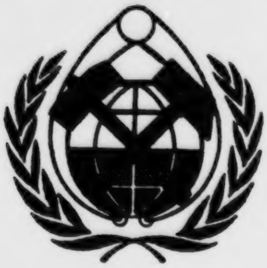


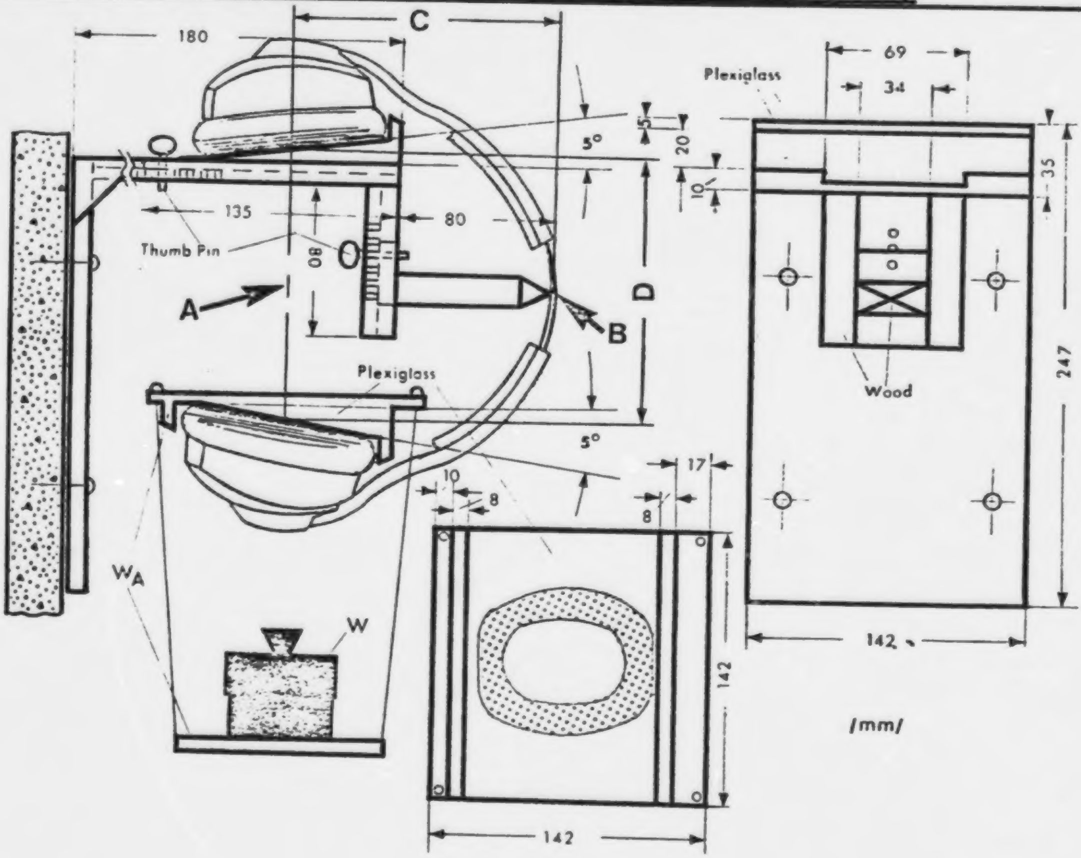
Ancient Egypt's tool in the modern mining environment

Vignette

APPENDIX A

Force Measurement Systems

Headband Force Apparatus (Elliot Lake Laboratory)


180
C
135
80
Thumb Pin
80
A
B
D
5°
5
20
10
5°
Plexiglass
Plexiglass
W$_A$
W
10
8
17
8
142
142
69
34
35
247
Wood
142
/mm/

Clamping force measurement of ear muffs with headband.

NOTES:

1) A: Centreline passes through pivot point of earcup attachment to headband.
   B: After correct head band distance is obtained (operator's head size), move out of the way for force measurement.
   C: Correct operator's head size.
   D: Bizygomatic Diameter (D).

2) Construction: Almost any material can be used: wood, steal, plexiglass, etc.

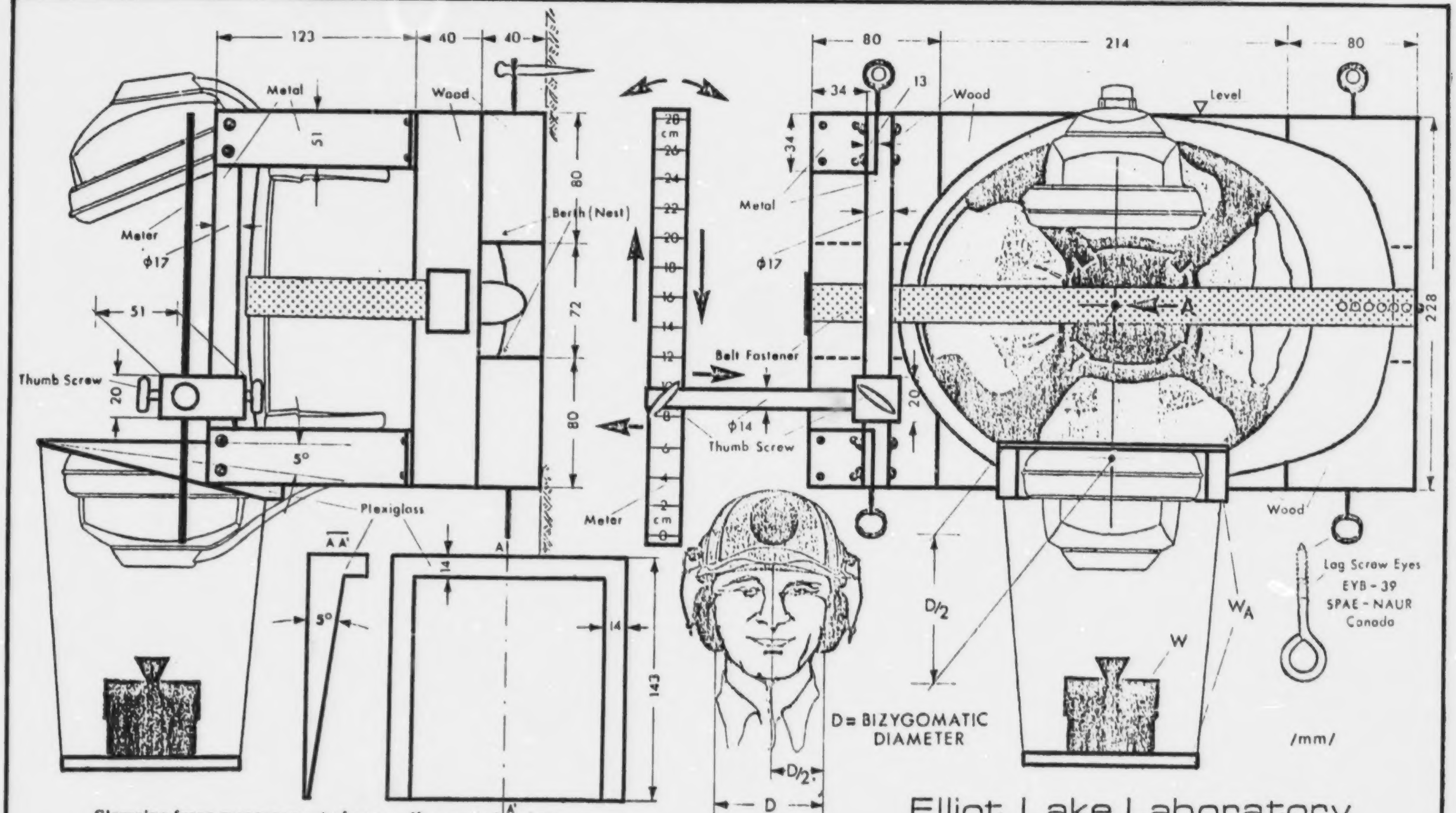
3) Calibration: No calibration. When measuring, the attachment weight must be taken into account. Clamping force (g wt) = $W_A + W$ (where W_A is the attachment weight, and W is the weight).

4) Operation: As shown in Fig. above.

5) Accuracy: ± 10 g.

Elliot Lake Laboratory
CANMET, E.M.R.
By: M.U.Savich

Apparatus for Clamping Force Measurements on Helmet (Elliot Lake Laboratory)


123
40
40
Metal
Wood
51
Meter
ϕ17
51
Thumb Screw
20
5°
Plexiglass
A A'
5°
14
14
143
A
A'
80
Berth (Nest)
72
80
28 cm
26
24
22
20
18
16
14
12
10
8
6
4
2 cm
0
Meter
Belt Fastener
ϕ14
Thumb Screw
80
34
13
34
Metal
ϕ17
Wood
20
214
Level
80
A
228
Wood
Lag Screw Eyes
EYB-39
SPAE-NAUR
Canada
W
W_A
D/2
D/2
D
D = BIZYGOMATIC DIAMETER
/mm/

Clamping force measurement of ear muffs mounted on helmets.

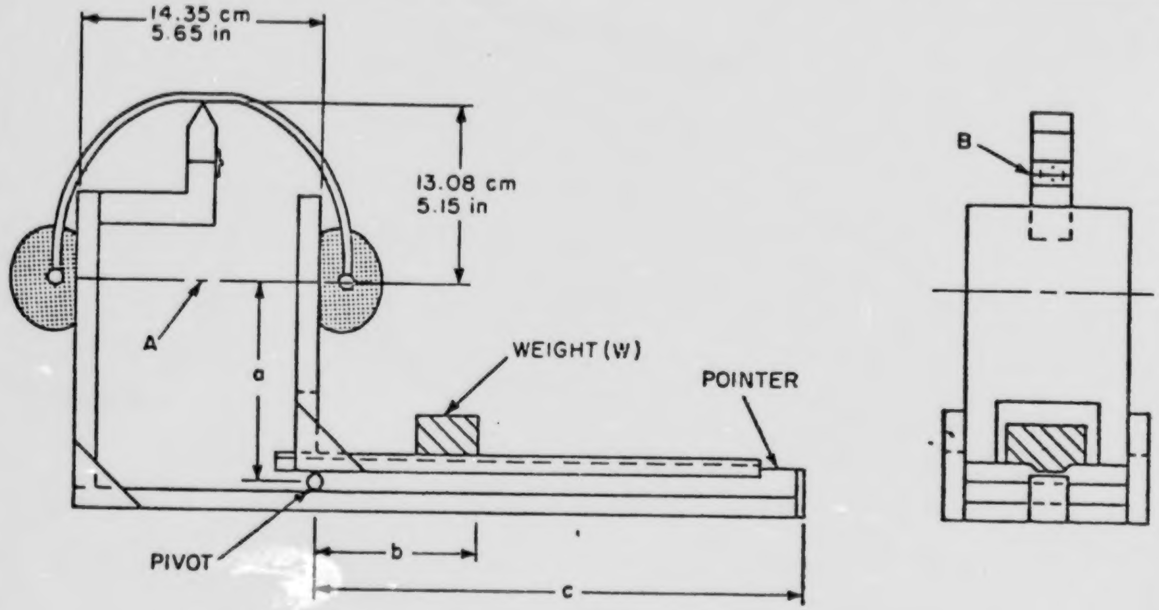
Elliot Lake Laboratory
CANMET, E.M.R.

NOTE:

1) A: Centreline passes through pivot point of ear cup attachment to hat (helmet).
2) Construction: Almost any material can be used: wood, steel, plexiglass etc.
3) Calibration: With lag screw eyes both edges of the apparatus are placed horizontally using a level. No calibration with weight.
4) Arrangement: The hat is placed on a berth (nest) lined with rubber and the belt fastener is well tightened.
5) Operation: Measurement should be done for one earcup first. The apparatus is then turned 180°, and measurement is done for the other cup. By this method, assymetry of clamping force can be measured. When measuring, the attachment weight must be taken into account. Clamping force (g wt) = $W_A + W$ (where: W_A is the attachment weight, and W is the weight).
6) Accuracy: ± 10 g.

By: M.U.Savich

Headband Force Apparatus
(ANSI S 3. 19-1974)



Force measurement system.

NOTES:

(1) A: Centerline passes through pivot point of earcup attachment to headband.

(2) B: After correct headband distance is obtained, move out of way for force measurement.

(3) *Construction:* Almost any material can be used providing that the units are made sufficiently rigid. The only critical dimensions are the earcup separation distance (14.35 cm or 5.65 in.) and the headband extension distance (13.08 cm or 5.85 in.). For best results, dimension "a" should be 12.0 cm (4.72 in.) to 15.0 cm (5.90 in.) and dimension "c" should be 30.5 cm (12 in.). A good free-working hinge with a small center pin is satisfactory as the pivot point. Weight is recommended to be about 900 g (about 2 lb).

(4) *Calibration:* With the pointer aligned, the distance between the two faces must be read 14.35 cm ± 0.2 cm. If the construction is such that the weight can be moved over the pivot point, then the zero force location is found by positioning the weight where it just balances. The force (F) at any location at a distance b that the weight has moved from the zero point is found by $F=bW/a$. A scale of grams (pounds) can be marked.

(5) *Operation:* The earmuff to be measured is positioned so that the points of attachment of the headband to the earcups are located at the centerline marks (13.08 cm) and the headband contacts the vertical post. The post is moved away, and the weight is positioned to where the pointers are aligned. The force is read from the scale which converts weight location into grams. When the pointers are aligned, the distance of 14.35 cm is automatically satisfied.

(6) *Accuracy:* The positioning of the earcup must be done with care in order to ensure that the point of attachment of the cup to the headband is the distance a from the pivot point. Practically, this is the largest source of error. With care, the position will be in error less than 0.3 cm for a maximum measurement error of 0.3 cm ÷ 12 cm = 2.6% (2.1 % for a = 15 cm). Actual measurements of ten different hearing protectors by three different persons have shown that 95% of the measurements will be within ±50g (about 2 ounces).

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Attenuation of ear muffs in

Canadian mines

1978

ATTÉNUATION DU BRUIT À L'AIDE DE CASQUES ANTIBRUIT DANS LES MINES CANADIENNES

par

M. Savich*

RÉSUMÉ

De nos jours, les casques antibruit font partie du matériel de sécurité utilisé dans les mines canadiennes et, partant, nous avons mené une étude sur l'efficacité de ces casques.

Les principales caractéristiques de onze casques antibruit disponibles dans le commerce ont été étudiées par :

1) une méthode psycho-physique
2) une méthode physique

Nous avons observé les effets suivants :

- la taille de la tête influe considérablement sur l'atténuation en raison de la différence dans la force de serrage;
- la quantité de cheveux emprisonnés entre les coussinets et la tête a un effet important sur l'atténuation par le casque antibruit;
- il n'y a pas de relation entre l'atténuation et le confort;

Mots-clés : Casque antibruit, force de serrage, confort, atténuation, laboratoire, mines.

* Chercheur, Laboratoire d'Elliot Lake, Laboratoires de recherche minière, Centre canadien de la technologie des minéraux et de l'énergie, ministère de l'Énergie, des Mines et des Ressources, Elliot Lake (Ontario).

- l'atténuation diminue lorsqu'on utilise des lunettes avec leur adapteurs. Les adapteurs ne constituent pas des barrières efficaces;
- on n'observe pas de grande différence dans l'atténuation lorsque le cou bouge;
- les casques antibruit de diverses marques n'ont pas la même efficacité;
- les casques antibruit dont la surface des coussinets est petite deviennent efficaces plus rapidement car la force par unité de surface est plus grande;
- une force de serrage supérieure à 900 (g pds), dans les principaux casques antibruit, ne se traduit pas par une plus grande atténuation;
- il existe une certaine coïncidence entre les caractéristiques d'atténuation (ANSI Z23.22 - 1957) des casques antibruit et les essais physiques.

Neuf casques antribuit parmi les onze ont été essayés dans des conditions uniformes dans des mines. Les trois meilleurs ont été sélectionnés. Ces trois casques se portent derrière la tête. Le casque antibruit doté d'une bande de soutien, qui améliore le confort et assure un bon ajustage, offrait la meilleure atténuation. Les raisons d'une mauvaise atténuation sont nombreuses : mauvaise installation des oreillettes sur le casque, mauvais ajustage, interférence due aux cheveux et aux lunettes, port incorrect par les mineurs, mauvaise supervision, formation des mineurs incomplète, etc.

Les résultats de l'étude montrent qu'aucun des casques antibruit essayés ne possède toutes les caractéristiques que l'on devrait retrouver dans un casque idéal.

Étant donné l'atténuation insatisfaisante offerte par le casque antibruit dans des conditions de travail (~ 15 dBA), il devrait être exigé que les travailleurs portent un casque antibruit et des bouchons protecteurs seulement lorsque le niveau de bruit excède 105 dBA (certains auteurs recommandent 110 dBA).

Voici les clés de la solution au problème :

- le contremaître doit être en mesure d'aider les mineurs à porter correctement le casque protecteur et de faire appliquer le règlement;
- le programme doit être présenté aux mineurs;
- le contact avec les fabricants doit être constant.

ATTENUATION OF EAR MUFFS IN CANADIAN MINES

by

M. Savich*

ABSTRACT

Today, in Canadian mines, ear muffs are an essential part of safety equipment, and because of this, a research study was conducted to investigate the efficiency of ear muffs.

The main characteristics of eleven commercially available ear muffs were investigated in the laboratory and analyzed by:

1) A psychophysical method; and a
2) Physical method.

These investigations showed the following effects:

- head size has a significant influence on the attenuation because of a different clamping force;
- test showed that the amount of hair trapped between the ear muff cushion and the head decreased ear muff attenuation;
- attenuation and comfort are not in a causal relationship;
- with the use of glasses and their adapters attenuation decreases. The adapters are not effective sound barriers;
- there are no great differences in attenuation with neck movement;
- the efficiencies of various brands of ear muffs are not equal;
- ear muffs with a small cushion area start serving their purpose more quickly because the force per unit area is larger;
- a clamping force larger than 900 g wt, in most ear muffs, does not cause an increase in attenuation; and
- attenuation characteristics (ANSI Z24.22 - 1957) of ear muffs show some correlation with physical tests.

Key words: Ear Muff, Clamping Force, Comfort, Attenuation, Laboratory, Mines.

* Research Scientist, Elliot Lake Laboratory, Mining Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, Elliot Lake, Ontario.

Nine ear muffs out of the eleven were tested under uniform conditions in mines. Three ear muffs were found to be the best. All three ear muffs have bands passing behind the head. The ear muff with a support strap, which improves comfort and maintains a good fit during wear showed the best attenuation. Causes of poor attenuation are numerous: bad mounting of ear muffs on helmets, improper fitting, interference by hair and eye glasses, improper wearing by miners, unsatisfactory enforcement by supervisory personnel, incomplete training of miners, etc.

Results of this research have indicated that none of the ear muffs tested in this study contain all of the characteristics desirable in an ideal unit.

Because of unsatisfactory ear muff attenuation in working conditions (15 dBA) it should be a mandatory requirement that workers wear both ear muffs and ear plugs if the noise level is higher than 105 dBA (various literature recommends 110 dBA).

The key to the solution lies in the following:

- the foreman must be capable of helping and controlling miners in their task of wearing ear muffs properly;
- the program must be introduced to miners; and
- constant contact must be maintained with manufacturers.

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1. INTRODUCTION

Miners exposed to high noise can become temporarily or permanently deafened. Noise can destroy cells in the inner ear. The resulting damage is usually detected by the change in the threshold of hearing. The major benefit of engineering control through hearing protector usage in Canadian mines is that a number of miners will be protected from a hearing impairment.

The aims of the ear muff studies are outlined in Fig. 1 under three general headings:

1) Factory procedures;
2) Laboratory tests in the Elliot Lake Laboratory; and
3) Underground mine.

Results obtained under the three general headings were computed and compared.

The author did his research by using simplified methods and simple equipment, which he developed in the Elliot Lake Laboratory.

2. EAR-PROTECTIVE DEVICES

The benefits of reduced noise in mines fall under two categories:

1) The benefits of reduced risk of hearing loss; and
2) The benefits relating to more pleasant working conditions.

There are three basic elements which should be kept in mind in noise and vibration control: a source, a path, and a receiver. The criteria and exposure limits should be established, supplemented and revised regularly in the light of current knowledge and data. The prevention of

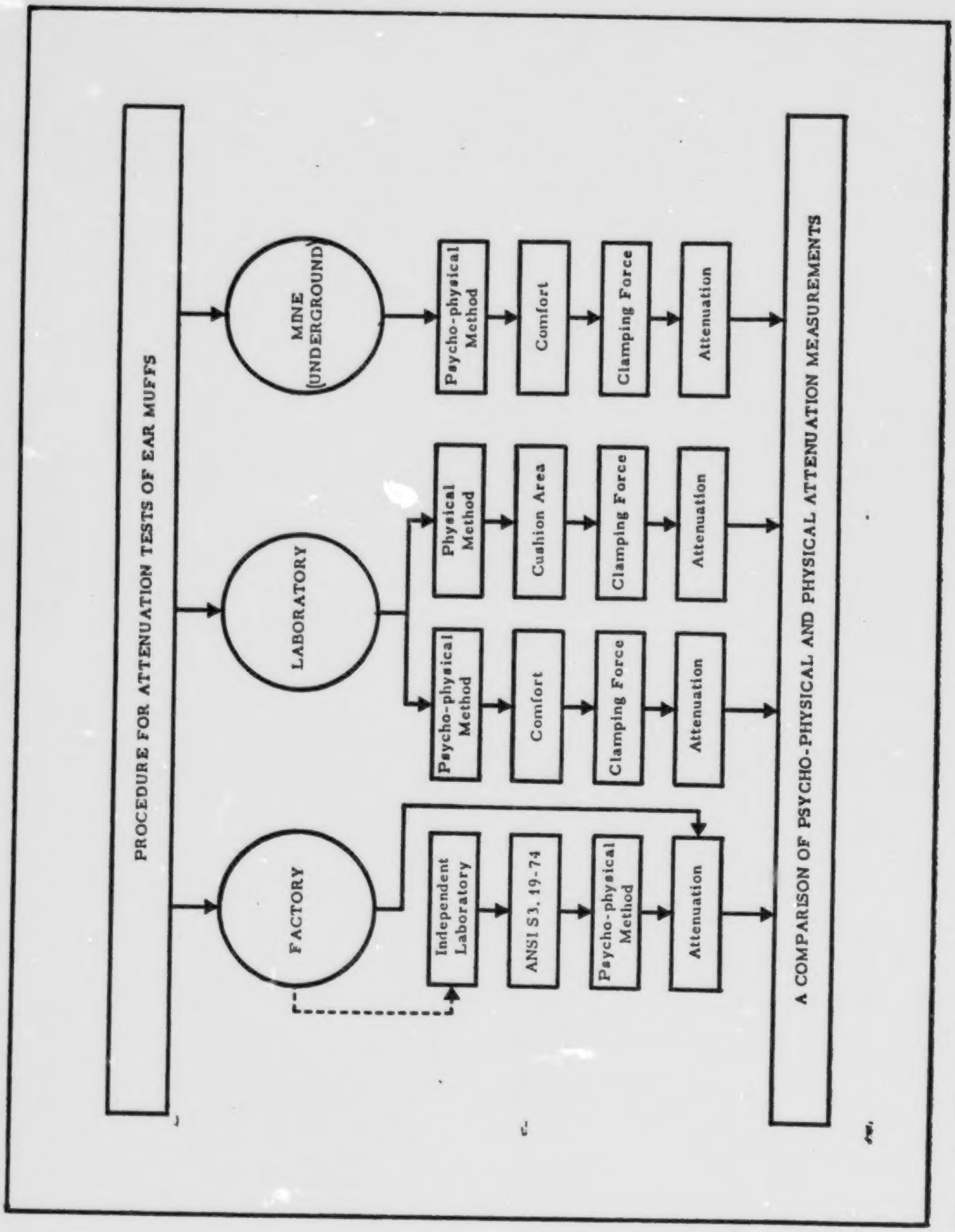

PROCEDURE FOR ATTENUATION TESTS OF EAR MUFFS
FACTORY
LABORATORY
MINE (UNDERGROUND)
Independent Laboratory
ANSI S3.19-74
Psycho-physical Method
Attenuation
Psycho-physical Method
Comfort
Clamping Force
Attenuation
Physical Method
Cushion Area
Clamping Force
Attenuation
Psycho-physical Method
Comfort
Clamping Force
Attenuation
A COMPARISON OF PSYCHO-PHYSICAL AND PHYSICAL ATTENUATION MEASUREMENTS

Fig. 1: Flow sheet diagram of attenuation test procedure of ear muffs in the Elliot Lake Laboratory.

occupational hazards in the working environment due to noise and vibration should be kept within limits (1) by:

a) technical measures;

b) supplementary administrative measures, where the technical measures alone do not provide sufficient protection.

Where such measures do not make it possible to bring noise and vibration within the limit.

Often the noise level cannot be reasonably reduced at its source or by the use of acoustical materials and noise barriers. In such cases, some form of ear protection should be considered for those people who are exposed to the noise.

2. 1. The Effectiveness of Ear Protection Devices

The effectiveness of ear-protection devices depends on a number of physical and physiological factors: the nature of the noise, the duration of exposure, attenuation characteristics, and possibly other variables. For a person wearing hearing protection, sound energy reaches the inner ear by four different paths:

1) through bone conduction which in effect short circuits the protector;
2) transmitted by vibration of the protective device;
3) by passing through leaks in the protector (which is minimal); and,
4) in acoustic leaks around the protective device.

Ear-protective devices can be divided into four categories (Fig. 2) (2):

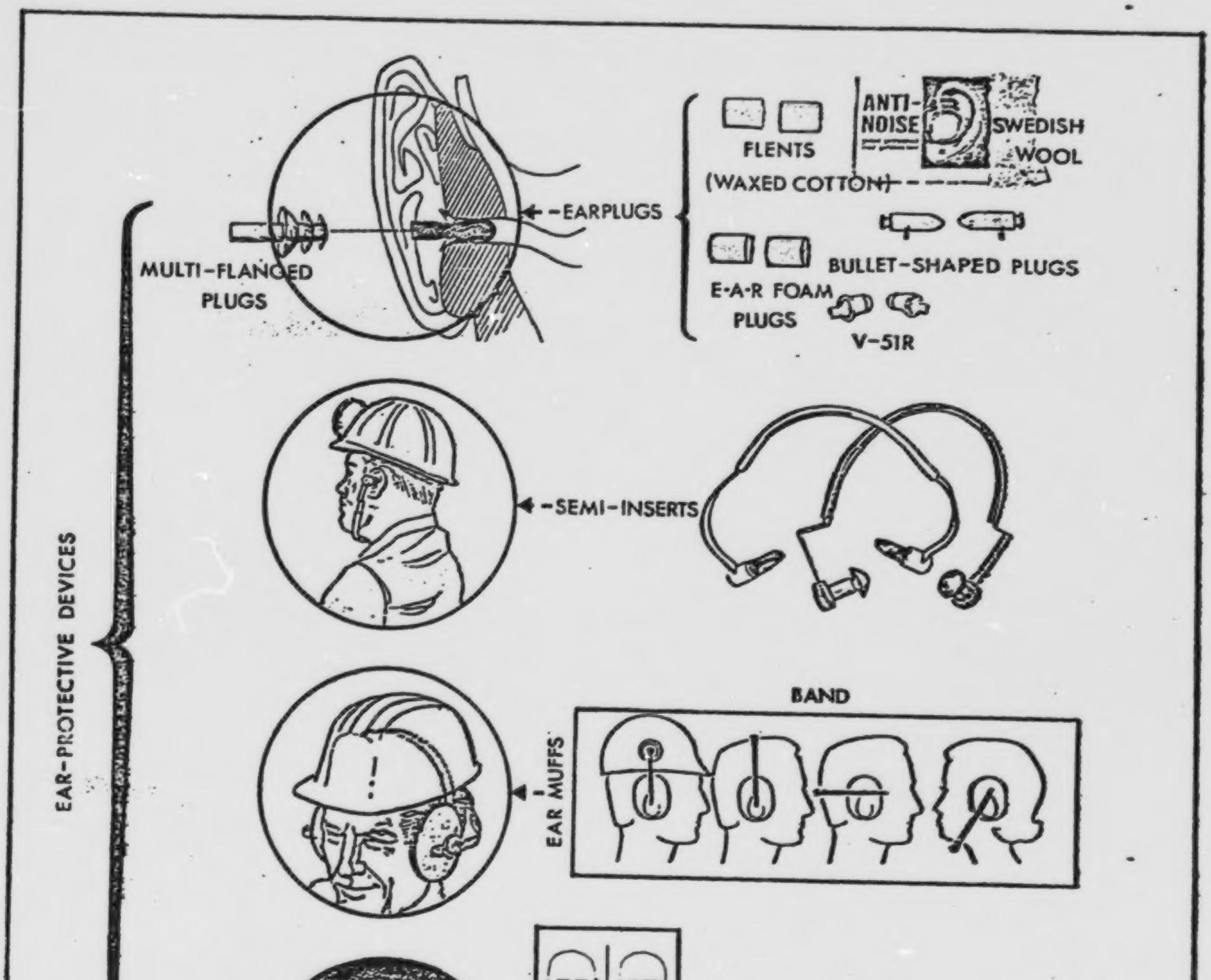

EAR-PROTECTIVE DEVICES
MULTI-FLANGED PLUGS
EARPLUGS
FLENTS
ANTI-NOISE
SWEDISH WOOL
(WAXED COTTON)
BULLET-SHAPED PLUGS
E-A-R FOAM PLUGS
V-51R
SEMI-INSERTS
EAR MUFFS
BAND
Hearing Protection
Eye Protection
Head Protection
Respiratory Protection
E-A-R FOAM PLUGS
HELMET
EAR MUFFS
INSERT PHONES
PERMANENT SOLUTION
CAB
SOUND-PROOF OFFICES (KEEP NOISE OUT)
EQUIPMENT ROOMS (KEEP NOISE IN)
By: M. U. Savich

Fig. 2: Ear-protective devices and a permanent solution for hearing protection.

1) Ear plugs (inserts) that fit into the ear canal. There are two types: pre-formed (e.g., moulded rubber, plastic, etc.) and non-preformed (e.g., waxed cotton).
2) Semi-inserts that provide an acoustic seal at the entrance to the ear canal and are supported by headset-type bands.
3) Ear muffs or cushions that cover the outer ear. In general, there are three types:
   a) foam cushions that fit around the ear and press against the head;
   b) fluid-filled cushions similar in size and shape to foam cushions; and,
   c) combination foam and fluid-filled cushions or foam and air-filled cushions.

   They may be held in place by a headband or a helmet.
4) Helmets that fit over the entire head represent a new development in over-all mine protection: hearing protection, eye protection, head protection and respiratory protection. The noise level is less than 70 dBA at the wearer's ears. The additional attenuation can be improved by ear plugs, ear phones or ear muffs (3). In these systems direct connection of ear muffs to helmets is not advisable because of sound transmission.

Ear protectors must comply with the following basic requirements:

1) To achieve high attenuation of ambient noise. The best ear protectors do not attenuate more than 25 to 30 dB. Attenuation is limited to about 50 dB because noise can by-pass the ear-protective

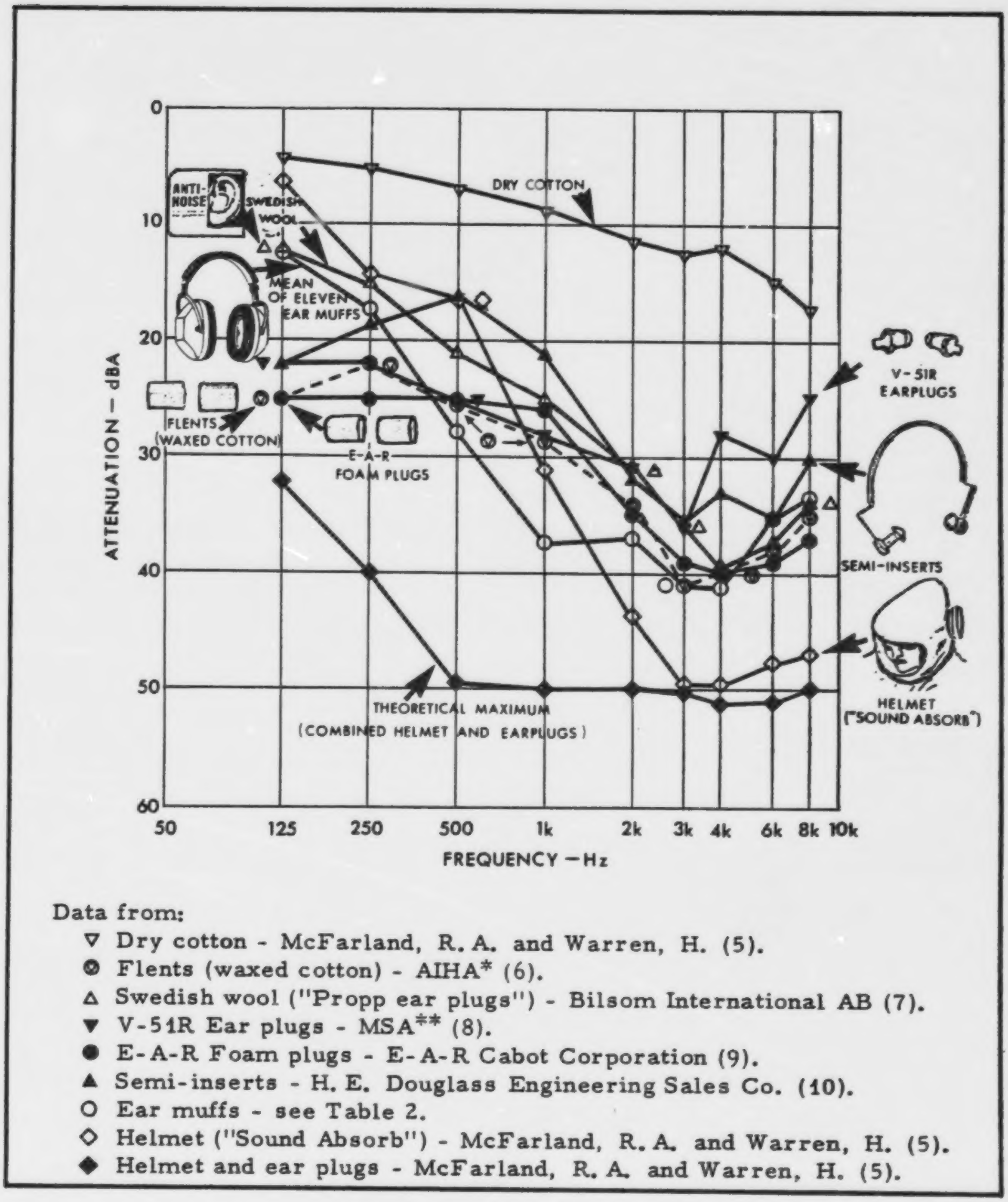
device by pick-up and by conduction through the bone of the head (4). Used by themselves, ear plugs are more effective in attenuation at low frequencies than are ear muffs (Fig. 3). Ear plugs and ear muffs can be worn at the same time to provide greater attenuation. The attenuation offered by the combination is less than the sum of the individual attenuations. This phenomenon has not yet been explained.

2) Be comfortable. An uncomfortable ear protector becomes intolerable after prolonged use.
3) Avoid harmful side effects; such as skin disorders.

2.2. Technical and Attenuation Data of Ear Muffs

Technical and attenuation data on ear muffs is given in Tables 1 and 2. Cushion areas, cup volumes and weight vary visibly. Cups are covered by foam on the inside for two reasons: to increase attenuation because uncovered cups permit entry of sound; and to prevent the formation of standing sound waves (the type of waves that are generated in seashells).

Several attempts have been made in the laboratory to increase attenuation using metal ear muffs, building in a Grason-Stadler earphone socket, adding one or more Helmholtz resonators, or by using soft hollow cushions filled with wax (11). The NRC type ear muff was developed at the National Research Council, Ottawa, by E. A. G. Shaw and G. J. Thiessen (12). This device when properly fitted may be worn for many hours without discomfort (13). Constant technical progress in ear muff design is evident by all manufacturers.



Data from:

- ▽ Dry cotton - McFarland, R. A. and Warren, H. (5).
- ⊗ Flents (waxed cotton) - AIHA* (6).
- △ Swedish wool ("Propp ear plugs") - Bilsom International AB (7).
- ▼ V-51R Ear plugs - MSA** (8).
- ● E-A-R Foam plugs - E-A-R Cabot Corporation (9).
- ▲ Semi-inserts - H. E. Douglass Engineering Sales Co. (10).
- ○ Ear muffs - see Table 2.
- ◇ Helmet ("Sound Absorb") - McFarland, R. A. and Warren, H. (5).
- ◆ Helmet and ear plugs - McFarland, R. A. and Warren, H. (5).

Fig. 3: Attenuation characteristics of ear-protective devices (ANSI+ Z24.22-57).

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* American Industrial Hygiene Association.

** Mine Safety Appliances Company.

+ American National Standards Institute.

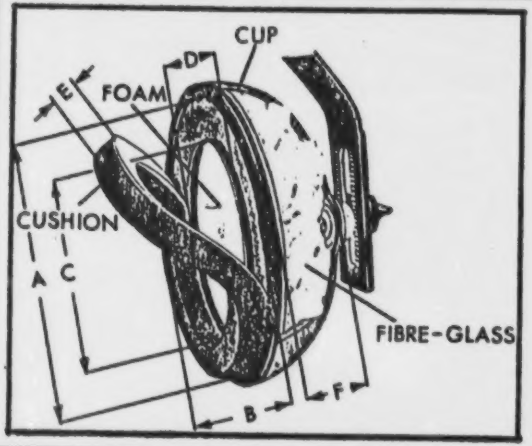


TABLE 1

Technical Data of Ear Muffs Acquired for Testing

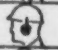
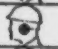
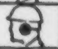
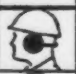
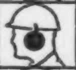
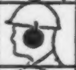
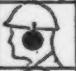
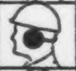
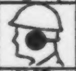
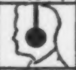
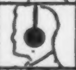
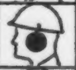
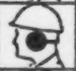
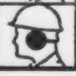
No.	Ear Muff	Filled Cushion	Band	Cross-sectional Dimensions (cm)						Area of Cushion (cm²)	Volume of Cup (cm³)	Weight (g)					Total Weight of Ear Muff (g)
				A	B	C	D	E	F			Cup	Cushion	Foam	Fibre-Glass	Σ wt	
1	A	Foam		9.7	9.7	6.5	4.3	1.1	4.2	48.0	180	49.86	13.67	7.61	-	71.14	185
2	B	Air		9.5	9.5	6.5	4.2	0.8	4.8	40.0	159	73.45	11.44	3.90	-	88.79	284
3	C	Foam		10.7	8.0	6.7	4.0	1.0	3.6	35.6	117	51.13	5.79	0.59	2.46	59.97	188
4	D	Foam		10.5	8.0	6.8	4.1	0.9	3.8	28.5	131	45.30	4.49	1.11	-	50.90	182
5	E	Foam		10.6	8.0	6.8	4.2	1.0	3.8	28.0	131	42.80	4.43	1.27	-	48.50	151
6	F	Foam		9.8	8.3	6.5	3.9	1.0	4.5	43.1	158	63.40	10.47	8.07	-	81.94	291
7	G	Fluid		11.0	8.3	6.3	3.6	0.7	4.4	38.7	167	68.64	56.29	2.90	-	127.83	335
8	H	Foam		11.0	8.3	6.4	3.7	0.8	4.4	42.5	164	57.02	19.87	4.91	-	81.80	274
9	I	Foam		9.4	6.9	6.9	4.6	1.0	4.4	26.7	171	73.94	8.92	3.21	-	86.07	278
10	J	Foam		9.4	6.9	6.9	4.6	0.9	4.4	24.5	171	76.26	9.05	3.34	-	88.65	275
11	K	Foam		11.0	8.2	6.5	4.2	1.0	3.6	42.2	141	52.92	15.92	2.48	-	71.32	295
Σ	Arithmetic Mean of all Ear Muffs			10.24	8.2	6.62	4.13	0.93	4.17	36.16	153.6	59.50	14.58	3.58	2.46	80.12	248
	Std. Dev.			0.68	0.86	0.21	0.32	0.12	0.4	7.98	20.4	12.16	14.63	2.46	-	29.25	60.5

TABLE 2

Attenuation Characteristics of Ear Muffs Acquired for Testing

No.	Ear Muff	Band	Attenuation (dB)*									
			Characteristic	Frequency in Hertz								
				125	250	500	1k	2k	3k	4k	6k	8k
1	A		Measured	9.7	16.1	24.9	33.9	34.1	36.0	41.0	33.8	31.5
			Std. Dev.	3.2	2.5	2,8	5.1	2.9	5.6	5.7	6.6	5.9
2	B		Measured	5	13	22	31	31	41	36	28	21
			Std. Dev.	-	-	-	-	-	-	-	-	-
3	C		Measured	10	16	30	34	37	41	45	39	34
			Std. Dev.	-	-	-	-	-	-	-	-	-
4	D		Measured	11.5	16.5	26.5	36.5	38	38.5	44.5	39.5	-
			Std. Dev.	-	-	-	-	-	-	-	-	-
5	E		Measured	13.4	17.3	28.6	41.8	40.7	45.2	42.7	32.6	29.3
			Std. Dev.	3.3	3.9	3.0	3.4	5.6	4.6	5.3	4.1	4.7
6	F		Measured	17	18	29	36	38	44	44	43	43
			Std. Dev.	2.6	2.6	3.1	3.2	4.1	7.2	4.6	4.7	5.7
7	G		Measured	18	23	33	44	44	47	45	42	39
			Std. Dev.	-	-	-	-	-	-	-	-	-
8	H		Measured	18	23	33	44	44	47	45	42	39
			Std. Dev.	-	-	-	-	-	-	-	-	-
9	I		Measured	12	17	30	35	35	36	37	32	30
			Std. Dev.	2.5	3.0	4.6	5.6	4.5	4.3	4.2	4.1	2.9
10	J		Measured	10	17	28	37	36	44	39	32	30
			Std. Dev.	2.0	2.6	4.3	5.4	4.5	5.6	3.8	5.4	4.9
11	K		Measured	15	17	26	43	36	38	38	33	34
			Std. Dev.	5.2	3.9	8.8	3.6	4.9	6.6	6.8	1.3	5.3
Σ	Arithmetic Mean of all Ear Muffs			12.16	17.09	27.8	37.22	36.98	41.07	41.22	35.49	33.53
	Std. Dev.			3.86	2.47	3.09	4.31	3.58	3.9	3.49	5.0	7.36

* Attenuation characteristic measured in accordance with American National Standard Specification Z. 24. 22-1957 (from Factory Data).

2.3. Comfort: One of the Main Requirements of Ear Muffs

The comfort provided by ear muffs depends upon two factors:

1) the ear cushion seal against the head; and
2) the muff design.

2.3.1. Ear Cushion Seal Against the Head

The pressure of ear cushion seals against the head is a direct consequence of the clamping force, adjustment, softness and weight. Clamping force (Head force): The clamping force is the force exerted by an ear muff on the skin and it is the most important element of discomfort. The clamping force against the sides of the head varies between 500 and 1000 g wt (14). Pressure limits have not yet been specified for ear muffs, however, pressure against the head is an important aspect. The clamping force varies and depends on the bizygomatic diameter of the head. Adjustment: Ear muff adjustment obviously depends upon the shape and dimensions of a worker's head. To fulfil the criterion of a tight fit, the muffs should have the capability of moving the support up and down so as to be parallel with the wearer's ears. To make allowances for each person's unique head shape, they should also be rotational on a pivot point. An effective seal inside the cup prevents acoustical leakage around the bearing surface.

A poor linkage between the helmet and the cups hinders clamping force and comfort. Poor mounting of asymmetrical ear muffs is caused by two things; a shortage of manufacturer's data for hole locations on helmets and the poor mounting of ear muffs on helmets in mines.

A good solution is to use a support strap in conjunction with a safety helmet (Fig. 4). The strap provides support for all ear muff type protectors when worn behind the head (back-band with strap). This head-strap is adjustable over the head to avoid discomfort caused by the pull of gravity on the ear cups. It also helps maintain the ear cups in position.

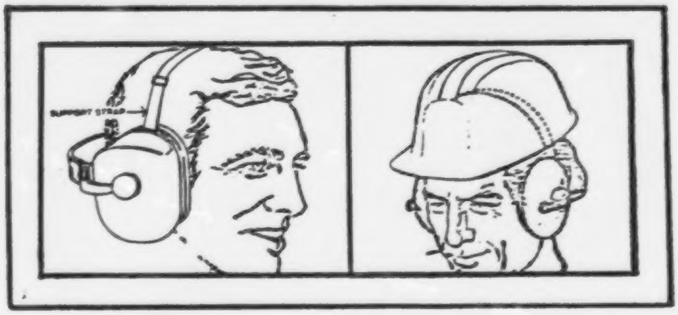
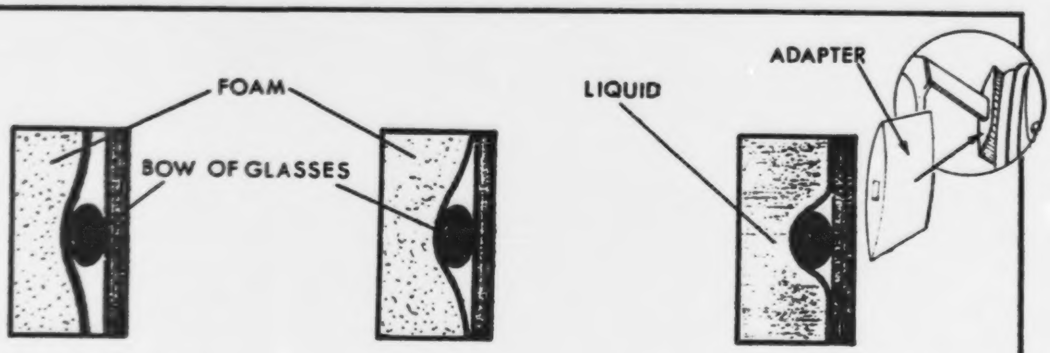


Fig. 4: Support strap: adjustable, lightweight, easily adaptable and comfortable.

Softness: Softness is a prime consideration for ear cushions. Apart from the vital aspect of comfort, an effective noise seal depends upon the cushion being soft enough to assume the contours of the head and to fit snugly around the frames of glasses or eyeglass adapters.

New materials for cushion seals perform the function of adapters. The No. 3 ear muff, model C, has foam filled cushions with covering material of soft, supple plastic film (Fig. 5). Some ear cups have special cushions with replaceable snap in/out foam over a liquid sealing ring to afford even pressure without gaps, even when wearing eye glasses.

Weight: The weight of ear muffs greatly affects comfort because the force of gravity adds to the irritants already present. The total weight of a pair of muffs varies between 151 g and 335 g (Table 1). For comfort the weight of



The cushion covering over the foam filling is too stiff and unpliable.

①

The cushion covering over the foam filling is soft and supple.

②

The cushion covering over the liquid — filling is very pliable.

③

Fig. 5: Material for cushion seals

an ear muff must be limited to approximately 200 grams (15).

2.3.2. The Design of Ear Muffs

Designing is an important requirement, especially for things that are worn. Two main factors in the design of ear muffs are: ease of handling, and choice of materials. Ear muffs should be functional and easily handled. Two properties facilitate ease of handling: mechanical simplicity and symmetry (2). Basic principles of mechanical simplicity demand that ear muffs be constructed so simply that instructions for their use are not necessary.

Ear muffs have different degrees of symmetry. Usually ear muffs are symmetrical, except those that are mounted on a helmet. Asymmetrical ear muffs mounted on helmets are a major source of poor attenuation.

2.4. Tests of Comfort

Ear muffs must be sufficiently comfortable to be worn for long periods of time, perhaps up to 8 or 10 hours a day. The comfort of ear muffs can be evaluated quantitatively, however, such a test has yet to be devised (2). Women were eliminated from the tests because there is no significant participation by them in mining industries (16). Qualitative evaluation was divided into three categories: 1) satisfactory; 2) good; and 3) very good. The experiment was designed so that the differences among age (rows) and qualitative evaluation (columns) represented a major source of variation. Such an arrangement is known as a Latin square (17). We used the method of industrial elimination in the parallel entries. This method is widely used in the selection of industrial products for the elimination of judges whose performance is erratic. A gray No. 7 ear muff, model G, with fluid filled cushions, and a yellow No. 8 ear muff, model H, with sponge filled cushions, were used. Comfort provided by these two ear muffs was relatively equal.

The summary of findings, relating data obtained from 27 subjects, is presented in Table 3. The results of an F-test confirmed a significant difference between muffs. By industrial elimination (muffs No. 7 and No. 8) we can determine which subjects are reliable and which ones are not. Ear muff No. 2 with foam and air filled cushions was chosen as the most comfortable of all. The data obtained from fourteen reliable subjects (mean age is 45.5 ± 3.09 years) show a significant difference between muffs (Table 4). Again, ear muff No. 2 was chosen as the most comfortable of all. No conclusions can be drawn from twelve subjects (mean age is 34.17 ± 2.37 years)

TABLE 3

Comfort Test of Ear Muffs Before Industrial Elimination

NO.	NUMBER OF SUBJECT	1	2	3	4	5	6	7	8*	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Σx^2	BAND
	EAR MUFF / AGE	19	24	28	28	29	29	30	30	30	30	37	38	38	40	40	42	42	46	46	47	49	52	52	55	57	59	60		
1	A	⬙	◆	◆	⬙	⬙	◆	◇	◆	◆	◆	◆	⬙	⬙	⬙	◆	◆	◆	⬙	◆	◆	⬙	⬙	⬙	◆	⬙	◇	⬙	74	
2	B	⬙	⬙	⬙	◇	◇	⬙	⬙	⬙	⬙	◇	◆	⬙	◆	⬙	◇	◇	⬙	⬙	⬙	◆	◆	⬙	⬙	◇	⬙	⬙	◇	131	
3	C	◆	◆	⬙	◆	⬙	⬙	◆	◆	◇	⬙	◆	◆	◆	⬙	◆	⬙	⬙	⬙	⬙	⬙	◆	◆	◆	◆	◆	◇	⬙	76	
4	D	◆	◇	◆	⬙	◇	◆	⬙	◆	◆	◆	◆	◆	◆	◆	⬙	◇	◆	◆	◆	◆	⬙	⬙	◆	◇	⬙	◇	◆	88	
5	E	⬙	◆	◆	⬙	◇	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	⬙	◆	⬙	⬙	◆	◆	50	
6	F	◇	◇	⬙	◇	◇	⬙	◆	◆	◆	◆	◆	◆	⬙	◆	⬙	⬙	◆	⬙	◆	⬙	◆	◇	◆	⬙	⬙	⬙	⬙	100	
7	G	◇	◆	⬙	◇	◆	◆	⬙	◇	◇	◆	⬙	◆	⬙	◆	◆	⬙	⬙	◇	⬙	◆	⬙	◇	⬙	◇	⬙	⬙	⬙	119	
8	H	⬙	◆	◆	⬙	◆	⬙	◇	◆	⬙	◆	⬙	⬙	◆	◇	◆	⬙	⬙	⬙	⬙	⬙	⬙	◇	⬙	◇	⬙	⬙	⬙	102	
9	I	⬙	◇	◆	◇	◆	⬙	⬙	◆	◇	◆	◆	⬙	◆	◇	⬙	◇	⬙	⬙	⬙	⬙	◆	⬙	⬙	◇	⬙	◇	⬙	117	
10	J	⬙	⬙	⬙	◆	◇	◆	◆	⬙	⬙	◆	⬙	⬙	⬙	◇	◆	⬙	◆	⬙	⬙	⬙	⬙	⬙	◇	◇	◆	⬙	◆	99	
11	K	◇	⬙	⬙	⬙	◆	⬙	◇	◆	◇	◆	⬙	◇	⬙	◆	◆	⬙	◆	⬙	◇	⬙	⬙	◇	⬙	◆	⬙	◇	⬙	122	
	Σx^2	53	44	29	58	57	29	42	25	52	25	23	34	26	29	28	53	26	43	37	29	29	61	37	65	38	66	40	1078	

NOTE: Evaluation
- ◆ Satisfactory (1)
- ⬙ Good (2)
- ◇ Very Good (3)

* Subject No. 8 had extremely opposite judgement of ear muffs 7 and 8 and must be eliminated in further calculations.

(131) Maximum

{ Industrial elimination }

```
ANOVA          12:46     06/09/77     THURSDAY     TO1

N-WAY ANALYSIS OF VARIANCE

FACTOR   LEVEL
  1        27 - SUBJECTS
  2        11 - MUFFS

LINE    VARIANCE *      SUM OF      DEGREES OF      MEAN
NO.     COMPONENT       SQUARES      FREEDOM       SQUARES

 1      CMP(     1)    29.11784        26          1.11992
 2      CMP(     2)    14.50505        10          1.45050
 3      CMP(    12)   104.58580       260          0.40225

           TOTAL      148.20870       296

* E.G., CMP(12) MEANS COMPONENT OF FACTORS 1 AND 2
GRAND MEAN        1.78451
```

LATIN SQUARE

```
LINE FOR (A), PLEASE ? 1
LINE FOR (B), PLEASE ? 3

F-RATIO = 2.78411 (D.F. = 26, 260)

LINE FOR (A), PLEASE ? 2
LINE FOR (B), PLEASE ? 3

F-RATIO = 3.60595 (D.F. = 10, 260)
```

Results of F Test

	Factor	Distribution	
		5% Level of Significance	1% Level of Significance
Muffs	3.61	1.83	2.32
Subjects	2.79	1.50	1.76

THE RESULTS SHOW A SIGNIFICANT DIFFERENCE BETWEEN MUFFS, BY INDUSTRIAL ELIMINATION (MUFFS 7 AND 8) WE CAN DETERMINE THE SUBJECTS THAT ARE RELIABLE AND THOSE THAT ARE NOT.

EAR MUFF NO. 2 WAS CHOSEN AS THE MOST COMFORTABLE OVERALL.

TABLE 4

Comfort Test of Ear Muffs Using Industrial Elimination

NO.	NUMBER OF SUBJECT	2	5	10	15	16	17	19	21	22	23	24	25	26	27 ← 14 SUBJECTS	Σx²	BAND
	EAR MUFF / AGE	24	29	30	40	42	42	46	49	52	52	55	57	59	60		
1	A	◆	⬙	◆	◆	◆	◆	◆	⬙	◇	⬙	◆	⬙	◇	⬙	40	
2	B	⬙	◇	◇	◇	◇	⬙	⬙	◆	◇	⬙	◇	⬙	⬙	◇	⓼⓷ 83	
3	C	◆	⬙	⬙	◆	⬙	⬙	⬙	◆	◆	◆	◆	◆	⬙	⬙	40	
4	D	◇	◇	⬙	⬙	◇	◆	◆	⬙	◆	⬙	◇	⬙	◇	◆	69	
5	E	◆	◇	◆	◆	◆	◆	◆	◆	◆	⬙	⬙	⬙	◆	◆	31	
6	F	◇	◇	◆	⬙	⬙	◆	◆	◆	◆	◇	⬙	⬙	⬙	⬙	56	
7	G	◆	◆	◆	◆	⬙	⬙	⬙	⬙	⬙	◇	◇	⬙	⬙	⬙	54	
	H	◆	◆	◆	◆	⬙	⬙	⬙	⬙	⬙	◇	◇	⬙	⬙	⬙	54	
9	I	◇	◆	◆	⬙	◇	⬙	⬙	◆	⬙	⬙	◇	⬙	◇	⬙	67	
10	J	⬙	◇	◆	◆	⬙	◆	⬙	⬙	◇	⬙	◇	◆	⬙	◆	56	
11	K	⬙	◆	◆	◆	⬙	◆	◇	⬙	⬙	◇	◆	⬙	◇	⬙	56	
	Σx²	43	56	24	27	49	22	33	25	33	52	56	34	62	36	562	

NOTE: Evaluation ◆ Satisfactory (1)
⬙ Good (2)
◇ Very Good (3)

(83) Maximum

{Industrial elimination}

```
ANOVA          11:05    06/09/77     THURSDAY      TO1

N-WAY ANALYSIS OF VARIANCE

                                   LATIN SQUARE
FACTOR    LEVEL
  1        14  -  SUBJECTS
  2        10  -  MUFFS

LINE   VARIANCE *    SUM OF     DEGREES OF     MEAN
 NO.   COMPONENT    SQUARES      FREEDOM      SQUARES

  1    CMP(     1)  16.94286        13         1.30330
  2    CMP(     2)  10.54286         9         1.17143
  3    CMP(    12)  49.05713       117         0.41929

           TOTAL    79.54283       139

* E.G., CMP(12) MEANS COMPONENT OF FACTORS 1 AND 2

GRAND MEAN         1.84286
```

Results of F Test			
	Factor	Distribution	
		5% Level of Significance	1% Level of Significance
Muffs	2.79	1.96	2.56
Subjects	3.11	1.80	2.26

RESULTS FROM RELIABLE SUBJECTS SHOW A SIGNIFICANT DIFFERENCE BETWEEN MUFFS. EAR MUFF NO. 2 WAS CHOSEN AS THE MOST COMFORTABLE OVER ALL.

```
LINE FOR (A), PLEASE ?
LINE FOR (B), PLEASE ? 3

F-RATIO  =  3.1083  (D.F.  =  13, 117)

LINE FOR (A), PLEASE ? 1
LINE FOR (B), PLEASE ? 3

F-RATIO  =  2.7938  (D.F.  =  9, 117)
```

who were shown to be poor judges. In the analysis, more value was placed on ear muffs with larger cushion areas (Table 1).

2.5. Head Size Survey

The variety of size, shape, and contour of the human head poses a difficult problem to the manufacturer of ear muff protective devices. The major reason for making the bizygomatic diameter survey was to evaluate the clamping force required in ear muff design.

A measurement of maximum distance between the bony structures (zygomatic arches) forward of the ears has been carried out on 27 men (Fig. 6).

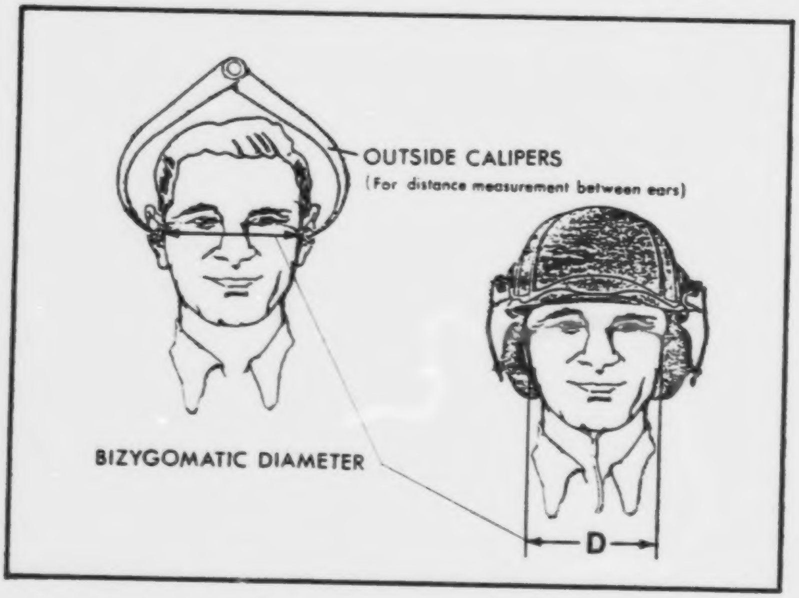


Fig. 6: Bizygomatic diameter measurement with calipers.

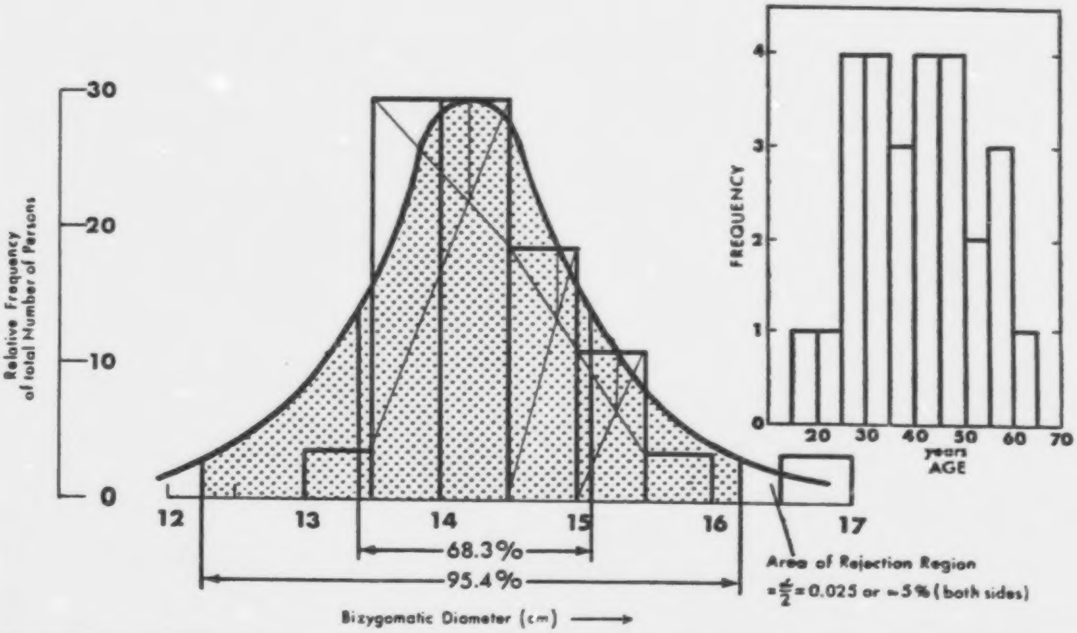
Statistical analysis of the samples showed that small, but significant differences existed between origin groups (Table 5). Subjects were grouped as to origin in the United Kingdom, Continental Europe, Asia, these regions being those represented by the population. The number of people of

TABLE 5

Bizygomatic Diameter Surveys

No.	Population	No. of persons	Means	
			D (cm)	Age (years)
1	Caucasian	20	14.47 ± 0.17	38.70 ± 2.55
2	Non-Caucasian	7	14.13 ± 0.26	43.29 ± 4.43
3	Canadian+	16	14.43 ± 0.16	38.94 ± 3.07
4	Non-Canadian+	11	14.23 ± 0.26	41.27 ± 3.18
5	U.K.++	13	14.17 ± 0.13	37.38 ± 2.90
6	Cont. Europe++	10	14.17 ± 0.28	45.20 ± 4.13
7	Slavic++	5	15.05 ± 0.50	44.80 ± 4.55
8	Asia+++	7	14.13 ± 0.26	43.29 ± 4.43
9	Age 19 - 39	13	14.05 ± 0.15	30.00 ± 1.48
10	Age 40 - 60	14	14.44 ± 0.19	49.07 ± 1.85
Σ	Canadian	27	14.35 ± 0.14	39.89 ± 2.21

+ 16 Canadian-born versus 11 non-Canadian-born.
++ U.K. origin, Cont. Europe origin, Slavic origin in Cont. Europe.
+++ Including Hungary and Finland.



Area of Rejection Region $= \frac{\alpha}{2} = 0.025$ or ≈5% (both sides) non-Caucasian origin is large, ~26 percent of the population.

In the literature, the volume of bizygomatic diameter data which has been published of Caucasian ethnic origin is relatively small. Comparison of results from Table 5, with other surveys from the literature, showed minor differences of no practical importance (18, 19, 20 and 21). Bizygomatic diameter surveys indicate that differences in head size may be sufficient to affect clamping force in some instances and give low attenuation or discomfort.

The standard ANSI S3. 19-1974 recommended for the measurement of clamping force used hearing protectors separated to a distance of 14. 35 cm between ear cups (medium head width).

3. LABORATORY TESTS OF EAR MUFFS

Measurements of ear muff attenuations have been made using two methods:

1. Psychophysical method using human heads by static range-of-movement:
   a) Movement of the joint of the neck in normal position. Subject used glasses and adapters.
   b) Movement of the joint of the neck, flexion, (dorsal and ventral) and neck rotation (right and left). Subject used glasses.
2. Physical method using apparatus for determining the efficiency of cup cushions.

These tests were made to provide performance data for eleven models of ear muffs under testing procedures established in the Elliot Lake Laboratory (Tables 1 and 2):

No. 1. Model A: often used in mills and workshops;

No. 2. Model B: is used in mines, but is no longer in production;

No. 3. Model C: is used in workshops and mines;

No. 4. Model D: is used in mines;

No. 5. Model E: is used in mines;

No. 6. Model F: is used in mines and mills;

No. 7. Model G: is used when helmets are not required;

No. 8. Model H: is used mainly in workshops and open-pits when mounted on helmet;

No. 9. Model I: is used by the military, particularly the navy, and in workshops, very little used in mines;

No. 10. Model J: is used by the military, in workshops and in mines; and

No. 11. Model K: is used mainly by industry and in mines.

3.1. Psychophysical Method

The ear muff attenuations had been measured as a transmission loss; the difference between the noise level outside the ear muff (measured 0.1 m from the side of the head) and that inside the ear muff (22). This method can be expected to give slightly different results than the American Standards Association's standard method (23, 24).

3.1.1. Equipment

A block diagram of the test equipment is shown in Fig. 7. The test signals were produced with a Brüel and Kjaer random noise generator, type 1402. An acoustical mirror was used to obtain a constant sound level of the test signal. The high powered loudspeaker was placed 1 m from the

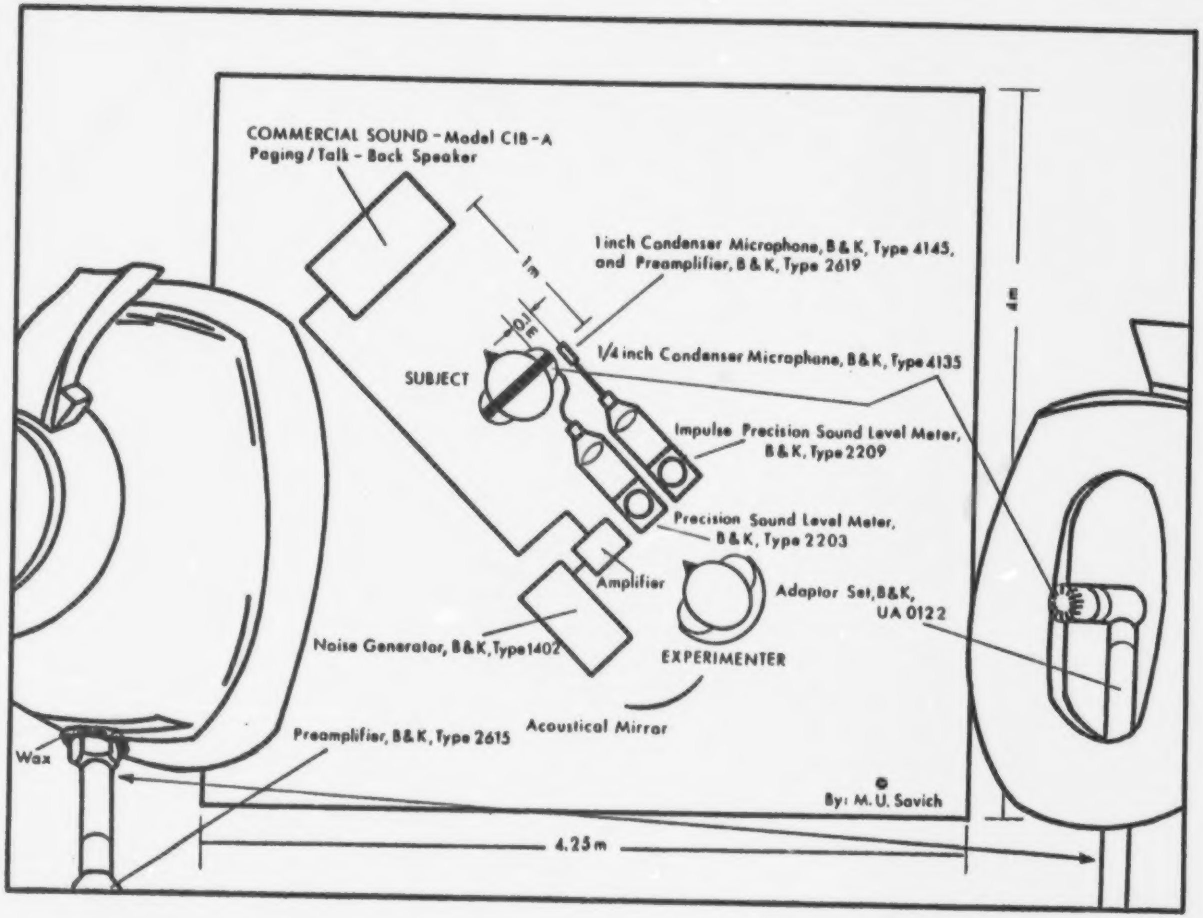

COMMERCIAL SOUND - Model C1B-A
Paging/Talk - Back Speaker
1m
0.1m
1 inch Condenser Microphone, B & K, Type 4145,
and Preamplifier, B & K, Type 2619
SUBJECT
1/4 inch Condenser Microphone, B & K, Type 4135
Impulse Precision Sound Level Meter,
B & K, Type 2209
Precision Sound Level Meter,
B & K, Type 2203
Amplifier
Adaptor Set, B&K,
UA 0122
Noise Generator, B&K, Type 1402
EXPERIMENTER
Acoustical Mirror
Preamplifier, B & K, Type 2615
Wax
4m
4.25m
©
By: M. U. Savich

Fig. 7: Block diagram of experimental instruments for measuring the attenuation of ear muffs.

subject. Microphones were suspended at the subject's ear: one under the cup and one over the cup, 1. 3 m above the floor, and located in the room's centre.

The basic system for measuring sound pressure levels with a sound level meter consists of the following:

1. Transducer:
    a) A 1 in., type 4145, B and K microphone was used over the cup.
    b) A $\frac{1}{4}$ in., type 4135, B and K microphone was used under the cup.
2. Preamplifier:
    a) A type 2619, B and K preamplifier was used over the cup.
    b) A type 2615, B and K preamplifier was used under the cup.
3. Sound level meter:
    a) Impulse precision sound level meter, type 2209, B and K. An octave filter, type 1613, B and K was connected to an impulse precision sound level meter.
    b) A precision sound level meter, type 2203, B and K. An octave filter, type 1613, B and K, was connected to a precision sound level meter.

The calibrator was a pistonphone, type 4220, B and K, and the sound level calibrator was a type 4230, B and K.

Two head band clamping force apparatuses were developed in the Elliot Lake Laboratory.

3. 1. 2. Subject Selection and Test Room

Two subjects for these tests were selected from the laboratory personnel. Subject 1 (age 35) with long hair, had a mezzocephalic head with a bizygomatic diameter of 13.6 (significantly smaller than average), and subject 2 (age 54) short haired, had a brachycephalic head with a bizygomatic diameter of 16.5 cm (significantly larger than average) (Fig. 8). In this case the human head replaced the dummy's.

The tests were conducted in a semi-reverberant room held at constant temperature, 4.25 m long, 4 m wide and 2.5 m high. The walls, ceiling and floor were constructed of wood and there was one window and one

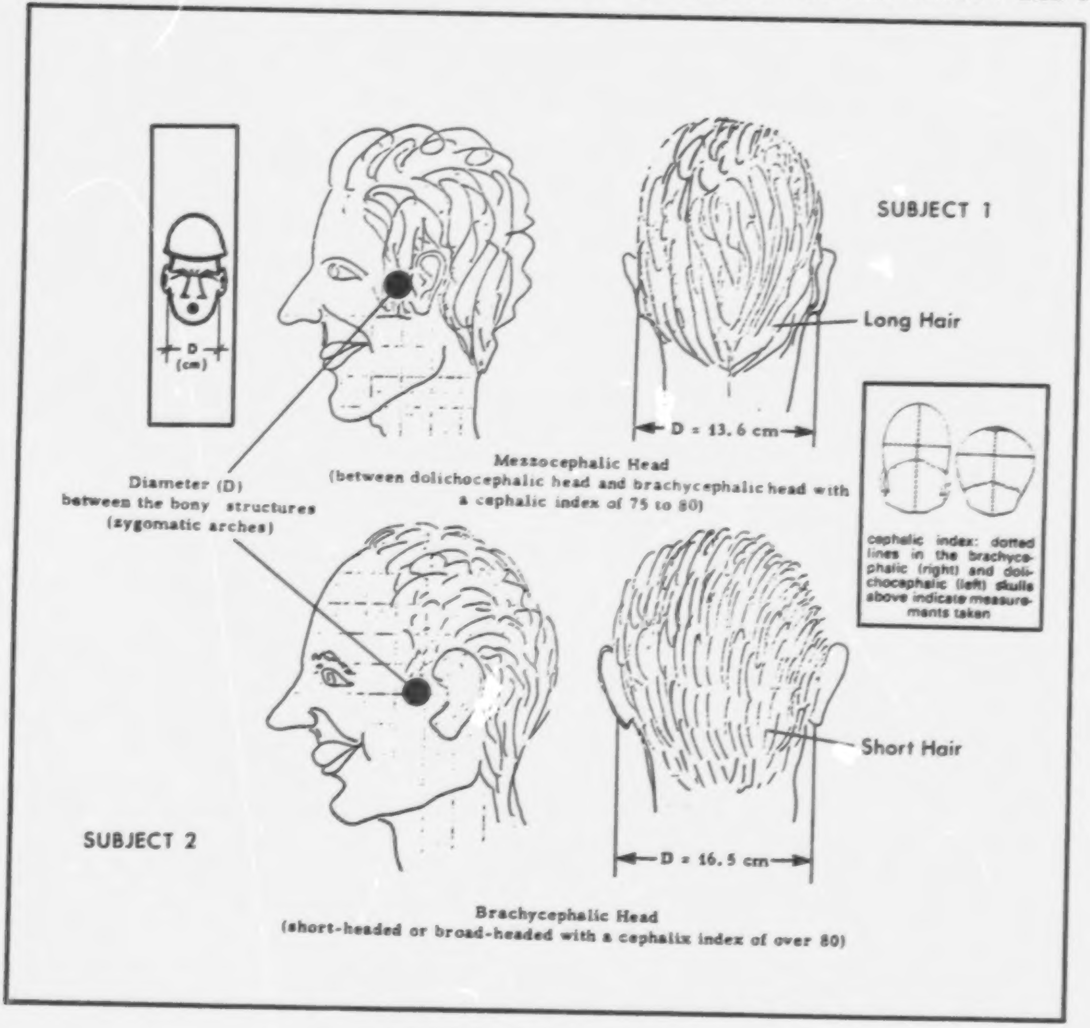

D
(cm)
SUBJECT 1
Long Hair
D = 13.6 cm
Mezzocephalic Head
(between dolichocephalic head and brachycephalic head with a cephalic index of 75 to 80)
Diameter (D)
between the bony structures
(zygomatic arches)
cephalic index: dotted lines in the brachycephalic (right) and dolichocephalic (left) skulls above indicate measurements taken
Short Hair
SUBJECT 2
D = 16.5 cm
Brachycephalic Head
(short-headed or broad-headed with a cephalix index of over 80)

Fig. 8: Subjects for psychophysical tests.

door in the room. The room was empty. Maximum ambient noise levels at the position of the subject (listener) were 35 dBA.

3. 1. 3. Test Procedure Using Human Heads

Fitting Procedure: Each of the subjects was taught the correct fitting procedures for the eleven models. The device was first positioned by the experimenter and then adjusted by the subject for a final orientation for each test.

Attenuation Measurements: Measurements of variation in sound pressure levels for a constant test signal level were made on both the left and right sides of the head. The ear muff attenuation was determined at the following frequencies: 125, 250, 1000, 2000, 4000 and 8000 Hz and at the dBA weighting network using the factory attenuations given in Table 2. Average noise levels of the test signals were calculated, and the noise reduction ratings for eleven ear muffs were determined (Table 6). There were 7 tests on both ears of two subjects, thus 28 sets of measurements in all. One ear muff had 4 extra tests.

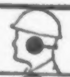
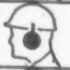
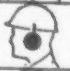
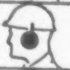
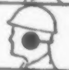
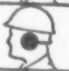
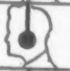
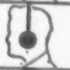
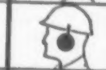
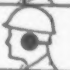
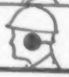
3. 1. 4. Effect of Glasses and Adapters on Attenuation of Ear Muffs

During this test the listener's neck joint was in normal position. The raw data of the attenuation tests of ear muffs are summarized in a graph (with frequency in hertz). Total noise was estimated from the octave-band noise levels. Approximate agreement with the total noise measured indicates a reasonably constant condition during the period of measurement.

Measurements of ear muff attenuations were made in the current series of tests with: (a) ear muffs, (b) ear muffs and glasses, and (c) ear muffs, glasses and adapter. Muff/eyeglass adapters were specially designed

TABLE 6

Test Signals and the Noise Reduction Rating of Ear Muffs During the Psychophysical Method of Measurement

No.	Ear Muff	Band	No. of Samples		Noise Level (dB)							dBA	* Reduction in dBA
					Frequency (Hz)								
					125	250	500	1000	2000	4000	8000		
1	A		28	Mean Std. Dev.	76.35 1.79	82.68 1.00	94.91 1.04	102.89 1.49	107.84 1.03	103.20 0.67	94.82 1.22	111.09	34.2
2	B		28	Mean Std. Dev.	74.25 0.78	79.32 0.48	91.41 1.05	98.89 1.15	103.86 1.05	100.36 1.25	91.95 1.29	107.44	31.1
3	C		28	Mean Std. Dev.	76.91 1.28	83.09 1.10	94.55 1.00	102.41 0.60	107.71 0.75	103.77 0.90	94.80 1.00	111.08	36.8
4	D		28	Mean Std. Dev.	74.60 0.55	79.48 0.40	91.89 0.84	99.09 0.79	104.91 0.99	100.21 0.99	92.80 1.53	108.06	37.5
5	E		28	Mean Std. Dev.	74.14 2.98	79.66 2.87	91.79 2.48	99.09 3.08	104.43 3.10	100.64 3.09	90.65 5.83	107.79	39.9
6	F		28	Mean Std. Dev.	76.89 0.35	82.91 0.89	94.32 0.97	102.00 0.81	107.86 0.86	103.36 0.72	95.39 1.00	111.07	38
7	G		32	Mean Std. Dev.	72.94 9.6	82.94 1.29	95.53 0.99	103.25 0.63	108.00 1.20	104.22 0.97	95.28 1.56	111.50	43.6
8	H		28	Mean Std. Dev.	76.88 1.30	83.06 1.24	94.16 3.92	102.34 0.47	108.57 1.10	103.41 1.10	95.89 1.59	111.57	43.6
9	I		28	Mean Std. Dev.	73.70 2.92	80.25 0.66	92.05 0.48	99.23 0.66	104.00 1.12	100.61 0.63	91.68 2.06	107.59	35
10	J		28	Mean Std. Dev.	77.05 0.87	82.07 1.14	95.07 0.86	102.64 1.41	107.59 0.79	103.61 0.96	95.14 1.05	111.01	36.3
11	K		28	Mean Std. Dev.	73.68 0.98	79.29 0.60	91.09 0.67	98.70 0.66	103.39 0.83	100.14 0.69	91.16 1.40	107.03	36.4
Σ-7	All Ear Muffs		10 (280)	Mean Std. Dev.	75.45 1.24	81.18 1.07	93.12 1.22	100.73 1.11	106.02 1.14	101.93 1.10	93.43 1.41	109.37	37.1
Σ	All Ear Muffs		11 (312)	Mean Std. Dev.	75.21 1.47	81.34 1.08	93.34 1.20	100.96 1.08	106.20 1.13	102.14 1.09	93.60 1.40	109.37	37

* Calculated from factory attenuation values (Table 2).

for people wearing glasses in conjunction with hearing protectors.

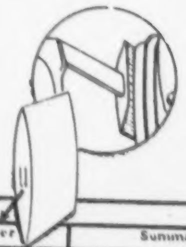
The attenuation was observed in a semi-reverberant field with sound directed at the face. Differences in attenuation of 10 dB or more were observed over all frequencies. The resulting differences in attenuation values over eleven ear muffs are found between subjects and between measurements on the same subject.

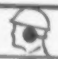
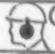
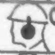
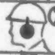
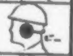
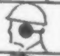
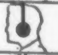
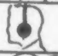
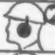
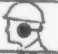
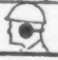
On the same subject, left hemisphere versus right hemisphere attenuation differed. Data reduction results were tabulated in the dBA weighting network so that a better understanding and clearer presentation were possible. Data analyses in reduced form for estimation of the degree of environmental hazard were presented in the situation of the neck joint in normal position (Table 7). From the summary results in Table 7 the following can be concluded:

1. Attenuation for subject 2 with large head and short hair was higher than attenuation for subject 1 with small head and long hair, except in four measurements.
2. Ear muffs No. 2, No. 5, and No. 8 had almost equal attenuations for both subjects.
3. The largest attenuation difference for both subjects occurred with the No. 6 ear muff, apparently due to subject 1's long hair. Substantial differences were also found with ear muffs No. 2, 7, 9 and 10.
4. With the use of glasses and their adapters, attenuation decreased. The adapters are not effective sound barriers.

TABLE 7

Attenuation Data Analysis in Reduced Form with the Neck Joint in Normal Position



No.	Ear Muff	Band	Subject		Clamping Force (g wt)	Attenuation (dBA)																	
						Muff					Muff and Glasses					Muff, Glasses and Adapter					Summary		
						Left Ear (L)	Right Ear (R)	$\frac{L+R}{2}$	(L + R) /2		Left Ear (L)	Right Ear (R)	$\frac{L+R}{2}$	(L + R) /2		Left Ear (L)	Right Ear (R)	$\frac{L+R}{2}$	(L + R) /2		$\frac{L+R}{2}$	(L + R) /2	
									Difference	Average				Difference	Average				Difference	Average		Difference	Average
1	A		1 2	13.6 16.5	580 780	28 34.25	26.5 28.25	26.25 31.25	+ 3	29.75	24.25 33.25	28 26.75	26.12 30	+ 3.88	28.06	16.5 32.25	26 19.25	22.25 25.75	+ 3.5	24	25.54 29	+ 3.46	27.27
2	B	 ①	1 2	13.6 16.5	1005 1355	29.75 37	31.5 31.5	30.62 34.25	+ 3.63	32.43	27 35	25.25 34	26.12 34.5	+ 8.48	30.31	24.5 29.5	21 30	22.75 29.75	+ 7	26.25	26.9 32.83	+ 6.33	29.66
3	C	 ②	1 2	13.6 16.5	730 930	26 30.5	31 28.25	28.5 29.37	+ 6.87	28.88	33 33	28 30	30.5 31.5	+ 1	31	31 32	26.25 31	28.62 31.5	+ 2.88	30.06	29.21 30.79	+ 1.58	30
4	D	 ②	1 2	13.6 16.5	980 1230	31.5 33.75	28.75 32.75	30.12 33.25	+ 3.13	31.68	30 31.5	25.75 30.25	27.87 30.87	+ 3	29.37	33 28.75	24 29.5	28.5 29.12	+ 0.62	28.56	28.83 31.08	+ 2.25	29.95
5	E		1 2	13.6 16.5	1980 2580	25 32.5	30.5 33.75	27.75 33.12	+ 5.37	30.43	36 32.5	30.5 33.75	33.25 33.12	- 0.13	33.18	32.25 29.25	30.75 31.75	31.5 30.21	- 1.29	30.85	30.83 32.12	+ 1.29	31.54
6	F		1 2	13.6 16.5	1180 1580	15.5 34.25	21.25 36.5	18.37 35.37	+ 17	26.87	14.25 33.25	20.5 33.5	17.37 33.37	+ 16	25.37	25.5 32.25	20.5 37.25	23 34.75	+ 11.75	28.87	19.58 34.5	+ 14.92	27.04
7	G		1 2	13.6 16.5	1230 1480	30.7 32.6	23.5 37.3	27.1 34.95	+ 7.85	31.02	30.4 34.1	17.4 34.4	23.9 34.25	+ 10.35	29.07	30.5 30.3	21.8 32.7	27.65 31.5	+ 3.85	29.57	26.21 33.56	+ 7.35	29.88
8	H		1 2	13.6 16.5	1130 1330	34 38.5	42.25 35	38.12 36.75	- 1.37	37.43	29.25 34.75	36 32.75	32.62 33.75	+ 1.13	33.18	31.25 32.5	37.25 33.75	34.25 33.12	- 1.13	33.68	35 34.54	- 0.46	34.77
9	I	 ②	1 2	13.6 16.5	730 1005	31.25 35.5	27 33	29.12 34.25	+ 5.13	31.68	29.25 37.75	28.25 33.75	28.75 35.75	+ 7	32.25	28.25 35.25	27 33.5	27.62 34.37	+ 6.75	30.99	28.5 34.79	+ 6.29	31.64
10	J		1 2	13.6 16.5	1330 1930	30.25 34.5	32.5 34.75	31.37 34.62	+ 3.25	32.99	29 33.75	31.75 34.5	30.37 34.12	+ 3.75	32.24	28.5 33	27 35.25	27.75 34.12	+ 6.37	30.93	29.83 34.29	+ 4.46	32.06
11	K		1 2	13.6 16.5	980 1280	23.5 28.25	27.25 31.5	25.37 29.87	+ 4.5	27.62	28 28.25	27 30	27.5 29.12	+ 1.62	28.31	24.5 27.75	25 26.5	24.75 27.12	+ 2.37	25.93	25.37 26.7	+ 2.83	27.29
1 - 11	Mean Std. Dev.	-	1	13.6	1077.7 377.9	27.77 5.13	29.45 5.44	28.61 4.72	+ (4.76 ± 2.23) Std. Error		29.22 5.44	27.11 5.08	27.67 4.44	+ (5.09 ± 2.06) Std. Error		27.98 4.36	26.32 4.60	27.15 3.75	+ (3.88 ± 0.94) Std. Error		27.81 3.86	+ (4.57 ± 1.92) Std. Error	
	Mean Std. Dev.	-	2	16.5	1407.3 502.3	33.78 2.84	32.96 2.97	33.37 2.32			33.37 2.35	32.15 2.52	32.76 2.09			31.16 2.23	30.95 4.86	31.03 2.97			32.38 2.22		
Σ	Mean Std. Dev.	-	1 & 2	-	1242.5 465.4	29.64 8.25	31.30 4.78	30.99 4.37		30.98 2.88	30.79 4.92	29.64 4.68	30.21 4.27		30.21 2.45	29.57 3.75	28.64 5.19	29.09 3.85		29.06 2.77	30.09 3.87		30.1 2.36

NOTE: ① Tested while mounted on helmet; B x 18A Safety Cap, CSA Standard Z 94.1

② Tested while mounted on helmet; Class C, CSA Standard Z 94.1

5. Most ear muffs show a lower attenuation than given by the factory specification:

Ear Muff No.	1	2	3	4	5	6	7	8	9	10	11
Noise Reduction* (dBA)	34.2	31.1	36.8	37.5	39.9	38	43.6	43.6	35	36.3	36.4
Attenuation** (dBA)	27.27	29.66	30	29.95	31.54	27.04	29.88	34.77	31.64	32.06	27.29
Difference (dBA)	6.93	1.44	6.8	7.55	8.36	10.96	13.72	8.83	3.36	4.24	9.11
Order of Performance ✿	5	1	4	6	7	10	11	8	2	3	9

NOTE: * From Table 6
** From Table 7
✿ 1 = best; 11 = worst

Only No. 2 ear muff came close to the factory attenuation value. The largest attenuation was displayed by ear muff No. 8.

3.1.5. Effect of Movement of Joint of the Neck, Flexion and Neck Rotation, on Attenuation of Ear Muffs

This test was similar to the previous one. The objective of this test was to see the stability of ear muffs on heads in motion, and to measure air leaks when wearing glasses. Ear muff attenuation measurements were performed in four positions (using one measurement) (Fig. 9).

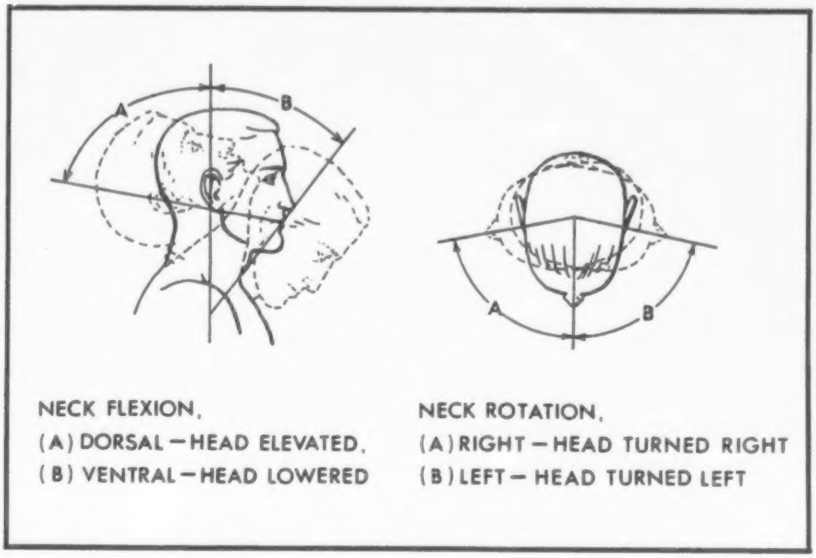

A
B
A
B
NECK FLEXION,
(A) DORSAL – HEAD ELEVATED,
(B) VENTRAL – HEAD LOWERED
NECK ROTATION,
(A) RIGHT – HEAD TURNED RIGHT
(B) LEFT – HEAD TURNED LEFT

Fig. 9: Neck flexion and neck rotation.

1. Neck flexion:
    a) Dorsal - head elevated;
    b) Ventral - head lowered.
2. Neck rotation:
    a) Right - head turned right;
    b) Left - head turned left.

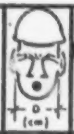
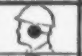
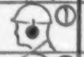
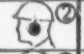
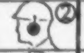
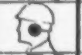
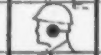
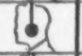
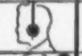
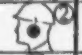
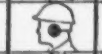
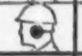
The left hemisphere was tested with glasses and the right hemisphere was tested without them. The tests were similar to the previous tests, because these events were often repeated.

The analyses of environmental data were presented in reduced form, for some intended purpose, such as estimation of the degree of environmental hazards in a situation where the neck joint is flexed and the neck rotated (Table 8). From the results in Table 8 the following can be concluded:

1. There are no great differences in attenuation when the neck moves;
2. The test performed on subject 1 (D = 13.6 cm) showed that the amount of hair trapped between the ear muff cushion and the head had a significant effect on ear muff attenuation.
3. The largest difference in attenuation between two subjects is once again with the No. 6 ear muff (left side 16 dBA, and right side 18.06 dBA).
4. The greatest attenuation occurred with the No. 10 ear muff on both subjects (34.21 dBA).
5. On the average, with both subjects, glasses decreased attenuation by 1.42 dBA.

TABLE 8

Attenuation Data Analysis in Reduced Form Where the Neck Joint is Flexed and the Neck Rotated

No.	Ear Muff	Band	Subject	 D (cm)	Clamping Force (g wt)	Attenuation (dBA)															
						Left Hemisphere with Glasses							Right Hemisphere without Glasses							Left and Right Hemispheres	
						Head elevated	Head lowered	Head turned right	Head turned left	Average	Difference	Total Average	Head elevated	Head lowered	Head turned right	Head turned left	Average	Difference	Total Average	Total Difference	Total Average
1	A		1 2	13.6 16.5	580 780	26.5 32.25	27 31.25	27.25 28.75	24.25 34.75	26.25 31.75	+ 5.5	29	30.5 31.75	29.25 32	32.5 35.25	27.25 29.25	29.87 32.06	+ 2.19	30.97	- 1.97	29.98
2	B	 ①	1 2	13.6 16.5	1005 1355	24.75 32.65	23.25 31.45	21 25	26.5 35.5	23.87 31.15	+ 7.28	27.51	27 31.5	32.25 33	29.25 33.5	25.25 32	28.44 32.5	+ 4.06	30.47	- 2.96	28.99
3	C	 ②	1 2	13.6 16.5	730 930	22 32.25	25.75 32.5	21.5 28.5	25 34	23.56 31.81	+ 8.25	27.69	28.75 36	32.25 34.75	29.75 36	30.25 33.5	30.25 33.56	+ 3.31	31.9	- 4.21	29.79
4	D	 ②	1 2	13.6 16.5	980 1230	28.25 34.5	32.75 30	29 30.5	35.5 36	31.37 32.75	+ 1.38	32.06	23.5 32.5	27.25 32	28.75 34.25	25.25 31.5	26.19 32.56	+ 6.37	29.38	+ 2.68	30.72
5	E		1 2	13.6 16.5	1980 2580	22.75 28	26 28	27.25 27	30.5 30.25	26.62 28.31	+ 1.69	27.47	30.25 28.75	29.75 28	29.25 31.25	22.75 24.25	28 28.06	+ 0.06	28.03	- 0.56	27.88
6	F		1 2	13.6 16.5	1180 1580	19.75 32	14.25 34.5	13.5 29.25	19.5 35.25	16.75 32.75	+ 16	24.75	26 37	16.5 39.75	22.5 38.25	15.25 37.5	20.06 38.12	+ 18.06	29.09	- 4.34	26.92
7	G		1 2	13.6 16.5	1230 1480	- -	- -	- -	- -	- -	-	-	- -	- -	- -	- -	- -	-	-	-	-
8	H		1 2	13.6 16.5	1130 1330	28.75 36.5	28.25 35.75	27.75 38.75	30 34.78	28.69 36.44	+ 7.75	32.56	26.25 39.5	21.75 38.75	25 36.25	19.75 41.75	23.19 39.06	+ 15.87	31.13	+ 1.43	31.84
9	I	 ②	1 2	13.6 16.5	730 1005	24.75 32.75	27.5 29.5	23.25 29.45	30.75 35	26.56 31.62	+ 5.06	29.09	27.75 24.5	25.25 33.25	27 36.5	28 33	27 31.8	+ 4.8	29.41	- 0.32	29.25
10	J		1 2	13.6 16.5	1330 1930	32.25 33.75	33.5 33	35 33.5	33 37.5	33.44 34.31	+ 0.87	33.87	34.7 35.25	33.8 34.5	32.45 36.25	36.7 32.75	34.41 34.69	+ 0.28	34.55	- 0.68	34.21
11	K		1 2	13.6 16.5	980 1280	26.25 28.75	23.75 30.5	20 27	28.25 34.5	24.56 30.19	+ 5.63	27.37	28.5 32.5	27.5 32.75	30.75 34.25	26 33.5	28.19 33.25	+ 5.06	30.72	- 3.35	29.09
1 - 11	Mean Std. Dev.	-	1	13.4	1077.7 377.9	25.6 3.64	26.2 5.38	24.55 5.96	28.32 4.66	26.17 4.59	+ (5.94 ± 2.15) Std. Error	-	28.32 3.06	27.55 5.29	26.72 3.15	25.64 5.8	27.56 3.92	+ (6.01 ± 2.24) Std. Error	-	-	-
	Mean Std. Dev.	-	2	16.5	1407.3 502.3	32.34 2.50	31.64 2.35	29.75 3.89	34.74 1.85	32.11 2.21			32.32 4.25	33.87 3.40	34.17 3.29	32.9 4.64	33.57 3.16				
Σ	Mean Std. Dev.	-	1 & 2	-	1242.5 465.4	28.97 4.6	28.92 4.91	27.15 5.58	31.53 4.77	29.14 4.65	-	29.14 2.84	30.32 4.15	30.71 5.41	31.95 4.18	29.27 6.31	30.56 4.64	-	30.56 1.81	-	29.87 2.05

NOTE: ① Tested while mounted on helmet; B x 18A Safety Cap, CSA Standard Z 94.1

② Tested while mounted on helmet; Class C, CSA Standard Z 94.1

6. Again the attenuation is less than the factory specification.

Ear Muff No.	1	2	3	4	5	6	7	8	9	10	11
Noise Reduction* (dBA)	34.2	31.1	36.8	37.5	39.9	38	43.6	43.6	35	36.3	34.4
Attenuation** (dBA)	29.98	28.99	29.79	30.72	27.88	26.92	-	31.84	29.25	34.21	29.09
Difference (dBA)	4.22	2.11	7.01	6.78	12.02	11.08	-	11.76	5.75	2.09	5.31
Order of Performance✿	3	2	7	6	10	8	-	9	5	1	4

NOTE: * From Table 6
** From Table 8
✿ 1 = best; 10 = worst

Ear muffs No. 2 and No. 10 had the best efficiency with reference to the factory attenuation. Also ear muff No. 10 demonstrated the best attenuation of all ear muffs.

3.1.6. Cushion Seals and Clamping Force

Manufacturers' specified attenuations were attained only on ear muffs No. 2 and No. 10 when worn on a large head with short hair, subject 2. The hair length had the largest effect on ear muff attenuation even though this ear muff has cushion seals that retain softness. With the use of glasses and adapters attenuation decreased substantially on small as well as large heads. Eye-glass adapters do not have the characteristics attributed to them in the literature (24). The cause is simple: new materials for cushion seals perform the function of adapters.

Attenuation mainly depends upon two factors: clamping force and cushion seals. From Tables 7 and 8 it is evident that an increase in clamping force results in an increased attenuation.

3.2. Physical Method

Ear muff attenuation was measured as the difference between the outputs of the microphone uncovered and the cup covered microphone. For this test the apparatus to determine the efficiency of cup cushions under different clamping forces was made in the Elliot Lake Laboratory (Fig. 10).

3. 2. 1. Instrumentation

The sound field of a pure tone at 500 Hz, 1000 Hz, 3000 Hz and 8000 Hz, was generated by a Hewlett-Packard test oscillator, model 650A. A loud-speaker was placed 1 m from the centre of the apparatus taken in horizontal and vertical directions. A microphone, type 4145, B and K, and a preamplifier, type 2615, B and K, were placed in the apparatus to determine the efficiency of cup cushions. The measurements were taken with an impulse precision sound level meter, type 2209, B and K, in the dBA weighting network. The measuring system used was calibrated by the pistonphone, type 4220, B and K, to measure band pressure level with reference to 20 μ Pa, (Pa = N/m^2).

3. 2. 2. Apparatus

The apparatus for determining the efficiency of cup cushions was constructed in accordance with the dimensions shown in Fig. 10. Both cups of an ear muff could have been tested on this apparatus separately, however, only one cup was tested.

Acoustical isolation of the apparatus was greater than 60 dB in any test frequency band in the range of interest. A sample test cup is shown in Fig. 10 (ANSI S 3. 19 - 1974).

3. 2. 3. Test Procedure

The ear cup was spread and placed on the plane plexiglass surface.

The steelyard's rubber pin was pressed against the ear cup and a clamping force was selected. Loss of attenuation by an ear cup under a constant clamping force and different pure tone test signal level was examined. These data demonstrate that the range of attenuation loss is approximately the same when ambient levels range from 80 dBA to 110 dBA. Output test signal data are presented in Table 9.

3.2.4. Measurement

The sound pressure levels at the microphone were measured for the acoustic test field without an ear cup. Afterwards, the hearing protector was placed over the microphone and the sound pressure levels were measured again. Readings are taken at the preferred centre frequency, and at the preferred clamping (head band) force. The measurements should be taken for right and left ear cups. When the measured difference between ear cups is 5 dB or greater, the attenuation of each ear cup should be reported (ANSI S 3.19 - 1974).

When the No. 5 ear muff was tested, comparison of attenuation was made with and without a chamois cloth between ear cup and plexiglass. No major differences between covered (with a chamois cloth) and uncovered plexiglass occurred except at 4 kHz (horizontal sound) where the difference was outside a tolerance limit. All tests were conducted without a chamois cloth.

3.2.5. Ear Muff Attenuation

The algebraic difference in sound pressure levels, in the dBA weighting network, at each test frequency signal, with and without the ear cup

TABLE 9

Output Test Signal Values

No.	Ear Muff	Horizontal Sound in dBA						Vertical Sound in dBA					
		Pure Tone Test Signal at Selected Frequency (Hz)						Pure Tone Test Signal at Selected Frequency (Hz)					
		500	1000	2000	3000	4000	8000	500	1000	2000	3000	4000	8000
1	A	90	100	105	100	100	80	90	100	110	95	100	80
2	B	90	100	105	100	95	80	95	105	110	100	100	80
3	C	95	100	105	100	100	80	95	100	110	100	95	80
4	D	90	100	105	100	100	80	95	100	110	95	100	75
5	E	95	100	105	100	100	80	100	105	110	95	100	80
6	F	95	100	100	100	90	80	90	100	110	95	100	80
7	G	90	100	105	100	100	80	95	100	105	95	95	75
8	H	95	100	105	100	100	75	95	105	110	95	100	80
9	I	100	100	95	100	100	80	95	100	110	90	100	80
10	J	95	100	105	100	100	80	95	105	110	100	100	75
11	K	95	100	105	105	100	80	100	105	110	100	100	75
	Mean	93.64	100	103.64	100.45	98.64	79.54	95.45	102.27	109.54	96.36	99.09	78.18
	Std. Dev.	3.23	0	3.23	1.51	3.23	1.51	2.70	2.61	1.51	3.23	2.02	2.52

in place on the plexiglass, is considered to be the attenuation of the device. The attenuation data and efficiency of cup cushions from three typical ear muffs were presented in graphic form (Fig. 11).

For a discussion of results, the clamping force at 450 g wt for one cup was used as a basic level (ANSI S 3. 19-1974). From the formula F = b W/a, used in the force measurement system, the clamping (head band) force will be 900 g wt if b = a. Also, attenuation characteristics measured in accordance with ANSI Z 24. 22-1957 are included so as to be compared with the efficiency of cup cushions. The ear muffs could be divided into three main groups:

Group	Ear Muff	Minimum Force (g wt)	Attenuation Behaviour
1	No. 4, No. 5, No. 8, No. 9, and No. 10	150 to 350	Steady at all frequencies and clamping forces above minimum
2	No. 1, No. 3, and No. 6	350 to 550	Steady at some frequencies and clamping forces
3	No. 2, No. 7, and No. 11	>550	Variable at all frequencies and clamping forces

In general, the attenuation values of ear cups are dependent upon two factors:

1. Clamping (head band) force (g wt), and
2. Design of the ear cup cushion.

Both factors were taken into consideration in this test. It is evident that attenuation is a function of size of air paths as shown by poor contact in Fig. 11. An air path causes different losses of attenuation at various frequency test signals as well as different losses among the various ear muffs.

A greater attenuation is obtained when an ear cup is exposed to horizontal sound, than when it is exposed to vertical sound (Table 10). According to acoustical laws, the opposite should be expected. E. A. G. Shaw came to the same conclusion and this phenomenon is yet to be explained (26).

From graphs, one can see developing a rudimentary theory to guide us in the design of ear muffs. Physical measurements of attenuation can provide valuable information.

This test explained the following:

1. Ear muffs with a small cushion area start serving their purpose more quickly because the force per square centimeter is larger;
2. A clamping force larger than 900 g wt, in the first and second groups, does not cause an increase in attenuation;
3. Attenuation characteristics (ANSI Z 24. 22-1957) of ear muffs show a correlation with physical tests. They cannot be completely compared because their values differ, dB versus dBA.

Based on the extensive literature and the physical tests performed, the apparatus for determining the efficiency of cup cushions can be used effectively to apply theory in the design of ear muffs.

4. EAR MUFF ATTENUATION TESTS IN MINES

A study was undertaken to measure ear muff attenuation in mines. A series of nine ear muffs was tested under uniform conditions in mines.

4. 1. Objective of the Study

The only certain means for evaluating the efficiency of the hearing protection program, equipment, training and supervision, is to measure,

TABLE 10

Attenuation of Ear Muffs with Horizontal and Vertical Test Signals

No.	Ear Muff	Horizontal Sound - Clamping Force 450 (g wt)						Vertical Sound - Clamping Force 450 (g wt)					
		Attenuation (dBA) of Pure Tone Test Signal at Selected Frequency (Hz)						Attenuation (dBA) of Pure Tone Test Signal at Selected Frequency (Hz)					
.		500	1000	2000	3000	4000	8000	500	1000	2000	3000	4000	8000
1	A	27	34	50	46	48	35	28.5	31.5	45	37.5	42	35.5
2	B	8	27	28	31	23	27	15	27.5	22	28	27	18.5
3	C	25	36	46	37	43	34	28.5	33	44	40	41.5	31
4	D	21	40	45	49	35	24	25.5	39	55.5	39.5	29	32
5	E	28	43	50	46	37	29	26.5	36.5	52	40	31	33
6	F	21	31	41	46	32	37	29	37	49.5	40	37.5	29
7	G	26	45	50	39	36	34	31	41	56	28.5	40	28
8	H	33	42	47	46	39	25	34	45	43	39	45.5	31.5
9	I	35	45	32	35	45	33	35	43.5	42	23	36	29.5
10	J	33	45	43	47	45	35	37.5	46.5	44	32.5	39.5	33
11	K	29	37	51	46	27	30	38.5	42	46.5	36.5	26	21
	Mean	26	38.64	43.91	42.54	37.27	31.18	29.91	38.41	45.41	34.95	35.91	29.27
	Std. Dev.	7.54	6.15	7.62	5.96	7.84	4.42	6.58	5.97	9.19	6.01	6.65	5.18

periodically, the hearing thresholds of all miners exposed to noise (6). However, this method does not detect problems until some hearing loss has occurred.

Because of this a new methed the 'Noise Dosimeter Vest' is being developed in the Elliot Lake Laboratory to provide an assessment of attenuation efficiencies of ear muffs in use.

4. 2. Attenuation Characteristics of Ear Muffs

Attenuation data on ear muffs was given in Table 2.

No. 7 and No. 8 ear muffs, model G and model H, were designed to be worn with the suspension over the head, thus making it impossible to wear a helmet at the same time. All of the other ear muffs were tested on each participant.

4. 3. Experimental Method

The Noise Dosimeter Vest provides a technical solution for the determination of the noise exposure index and the attenuation of ear muffs (Fig 12). It does so under the most difficult working conditions (i. e., single platform (giraffe), the load-haul-dump (LHD) vehicle, etc.).

These tests require only two dosimeters and a stop watch. The dosimeters have small microphones and provide accurate short time readings of the noise exposure index. Ear clips should be coloured differently according to intended use inside or outside an ear muff.

Also, a pocket-sized calculator designed for sound amplitude analysis should be utilized (dBA, Leq, Lmax and time duration of the sampling period).

The surveyor must measure the distance between the bony structures

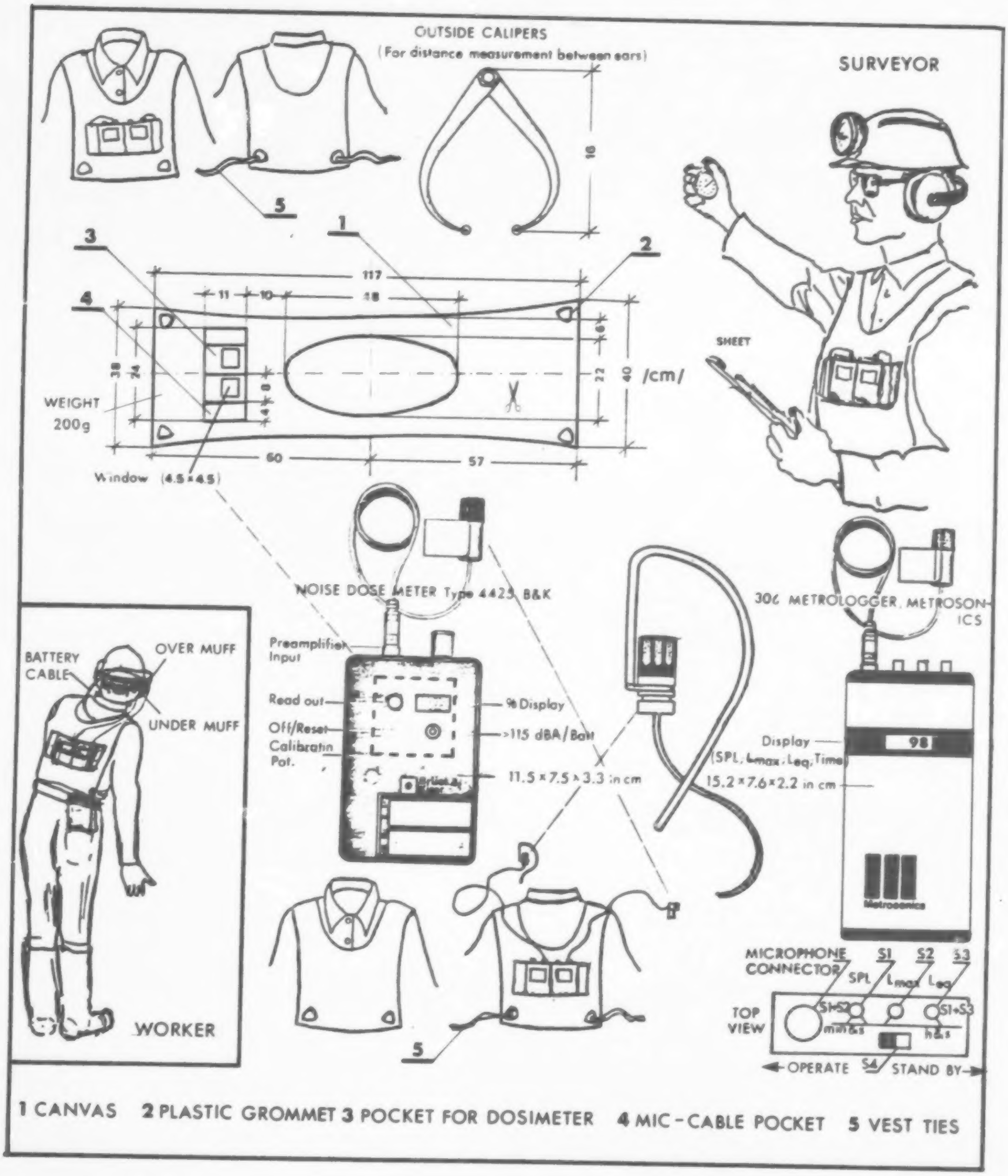

OUTSIDE CALIPERS
(For distance measurement between ears)
16
SURVEYOR
SHEET
5
1
2
3
4
117
11
10
48
6
38
24
8
4.5
22
40
/cm/
WEIGHT
200g
60
57
Window (4.5×4.5)
NOISE DOSE METER Type 4425 B&K
Preamplifier Input
Read out
Off/Reset
Calibratn Pot.
% Display
>115 dBA/Batt
11.5×7.5×3.3 in cm
306 METROLOGGER, METROSONICS
Display
(SPL, Lmax, Leq, Time)
15.2×7.6×2.2 in cm
98
Metrosonics
BATTERY CABLE
OVER MUFF
UNDER MUFF
WORKER
5
MICROPHONE CONNECTOR
S1
S2
S3
SPL
Lmax
Leq
TOP VIEW
S1+S2
S1+S3
min&s
h&s
OPERATE
S4
STAND BY
1 CANVAS
2 PLASTIC GROMMET
3 POCKET FOR DOSIMETER
4 MIC-CABLE POCKET
5 VEST TIES

Fig. 12: The noise dosimeter vest in use during ear muff attenuation measurements.

just forward of the ears (bizygomatic diameter) using an outside caliper. On the basis of bizygomatic diameter measurements, the clamping force can be evaluated. An apparatus was designed in the Elliot Lake Laboratory (Fig. 13), for the immediate measurement of clamping force at the mines. Evaluations are done on the spot and the worker is immediately informed about the noise exposure index level and ear muff attenuation data. If the attenuation is unsatisfactory, the cause will have to be investigated. Results are filed in the office.

4.4. Participants

In this study one man at each of three working sites was chosen:

1. Jumbo (Three Drills) Operator;
2. Drill Hydrofore Operator; and
3. Jaw Crusher Operator.

Of particular importance were the following items:

- The miner is informed of the test's objective;
- The miner is asked to adjust his own ear muffs to his particular liking, and to make qualitative evaluations of comfort before and after the test.
- If a miner wishes to withdraw at any time and for any reason, he may do so.

It was explained that all testing would be conducted under the full support of miners and supervisory personnel.

4.5. Results

The results of the study presented in Table 11, indicate poor attenuation of ear muffs in underground mining conditions. As a result of analyzing the data obtained, three major findings are presented below.

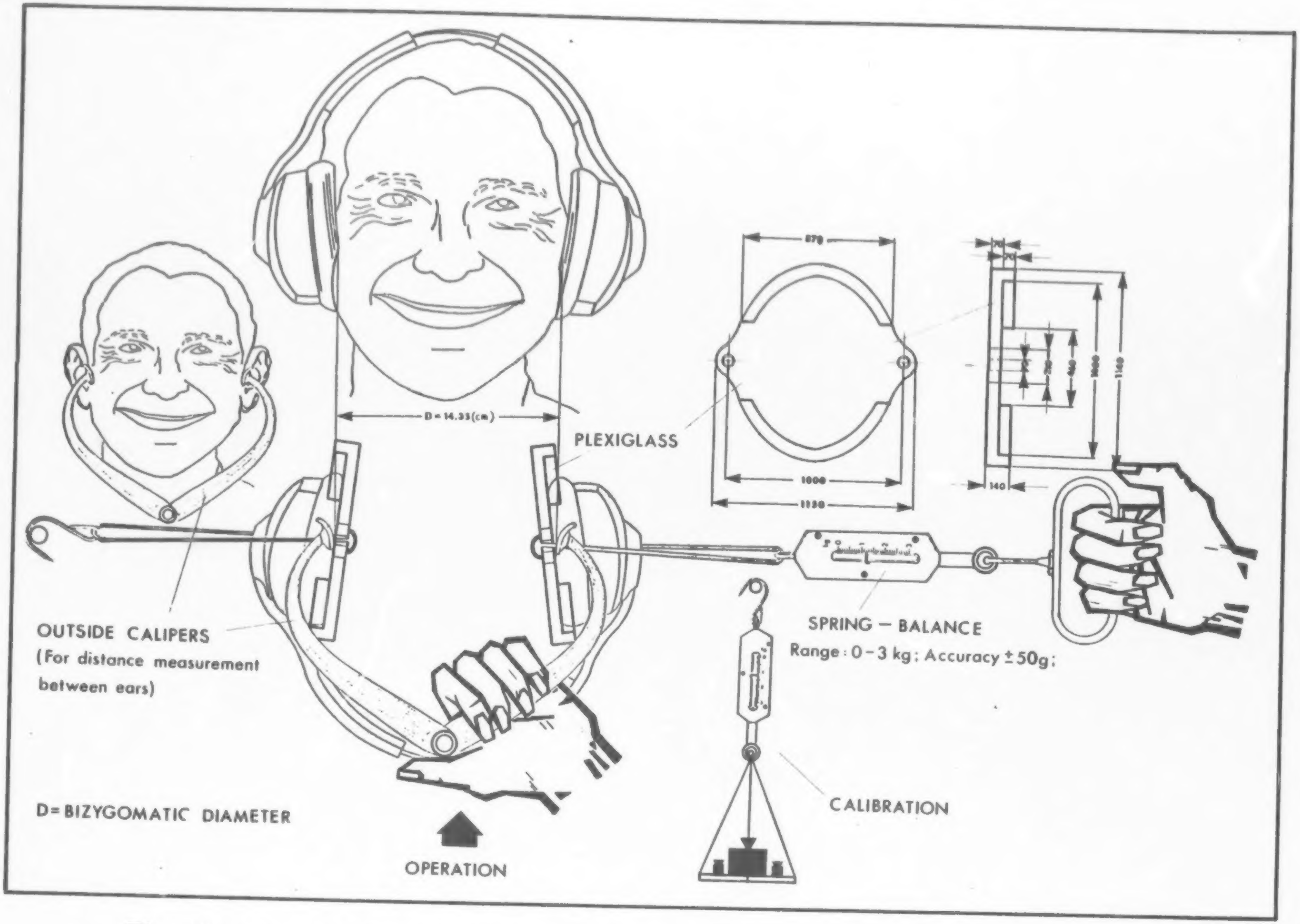

D = 14.35(cm)
PLEXIGLASS
870
1000
1130
140
1000
1140
OUTSIDE CALIPERS
(For distance measurement
between ears)
SPRING – BALANCE
Range: 0 – 3 kg; Accuracy ± 50g;
CALIBRATION
D = BIZYGOMATIC DIAMETER
OPERATION

Fig. 13: Clamping force measurement system in mines.

The clamping forces were calculated on the basis of measured bizygomatic diameters.

Jumbo (Three Drills) Operator: While working the jumbo operator used only ear plugs. The miner was of the opinion that his ear muffs were inefficient and wore them only because regulations required it. The ear muff was No. 6, model F, with hat mounting, that did not properly cover the ears. On the basis of obtained results, it is evident that the noise levels are high (115 dBA) and that the ear muffs supplied do not offer adequate protection (Table 11). For all ear muffs, one of the factors contributing to the low attenuation found was this man's extremely small head size. The ear muffs with adequate attenuation were Nos. 1, 2, 5 and 10. The jumbo operator judged ear muffs which are worn behind the head (Nos. 6 and 11) to be poor providers of comfort. Also, such ear muffs have poor attenuation (Table 11).

Hydrofore Drill Operator: Hydraulic drills are used increasingly on jumbo machines, replacing the heavy pneumatic rock drills (27). A hydrofore drill (hydraulic-electric fan) has no air exhaust noise and thus produces low noise levels at low frequencies. Because the attenuation of ear muffs is better at high frequencies, it should be expected that their efficiencies would be very high. Test results demonstrate that good attenuations were obtained by ear muffs Nos. 5, 6 and 10 (Table 11), with band passing behind the head. The other ear muffs did not provide

TABLE 11

Attenuation of Ear Muffs at the Jumbo (Three Drills), Drill Hydrofore and Jaw Crusher Operator's Stations

JUMBO (THREE DRILLS) OPERATOR — D = 12.8 cm

No.	Ear Muff	Band	Comfort	Clamping Force (g wt) L.S.*	R.S.*	B.S.*	Attenuation (dBA) L.S.	R.S.	Ave.	L_{eq} (dBA) L.S.	R.S.	Ave.
1	A		◈	-	-	430	20.8	14.2	18.65	115.5	115.1	115.3
2	B	①	◈	530	230	760	14.4	17.9	16.49	115	114.8	114.9
3	C	②	◆	580	630	1210	11.3	11.7	11.5	114.1	113.8	113.95
4	D	③	◈	930	1030	1960	12.3	14.6	13.6	116	112.9	114.45
5	E		◈	-	-	1830	28	20.2	25.66	117	117.6	117.3
6	F		◆	-	-	1080	9.6	7.2	8.56	114.4	116.4	115.4
7	G		-	-	-	1130	-		-	-	-	-
8	H		-	-	-	1030	-		-	-	-	-
9	I	④	◆	630	730	1360	4.8	0.6	3.19	115	112.1	113.55
10	J		◇	-	-	1230	~25	~25	~25	109.7	116.2	112.95
11	K		◆	-	-	830	11.5	12	11.76	114.3	115.8	115.05
Σ	Mean		-	-	-	1168	-	-	-	114.55	114.97	114.76
	Std. Dev.		-	-	-	443	-	-	-	2.04	1.77	1.27
	$\overline{SPL}^x$		-	-	-	-	-	-	-	114.9	115.3	115.1

DRILL HYDROFORE OPERATOR — D = 13.8 cm

No.	Ear Muff	Comfort	Clamping Force (g wt) L.S.*	R.S.*	B.S.*	Attenuation (dBA) L.S.	R.S.	Ave.	L_{eq} (dBA) L.S.	R.S.	Ave.
1	A	◆	-	-	580	13.5	11.5	12.6	103.8	106.2	105
2	B	◇	680	380	1060	11.4	12.6	12.04	104.3	107.1	105.7
3	C	◆	630	680	1310	10.3	4.2	8.25	106.6	106.9	106.7
4	D	◇	1030	1080	2110	11.5	9.1	10.46	104.8	104.6	104.7
5	E	◇	-	-	2080	27.2	21.7	25.26	104.2	108.7	106.4
6	F	◈	-	-	1230	25.6	23.4	24.64	104.3	102.3	103.3
7	G	-	-	-	1230	-		-	-	-	-
8	H	-	-	-	1130	-		-	-	-	-
9	I	◈	680	880	1560	6.4	5.1	5.80	104.9	103.3	104.1
10	J	◈	-	-	1380	15.8	19.8	18.24	102.8	103.3	103.0
11	K	◇	-	-	930	10.4	9.5	9.97	104.9	103.9	104.4
Σ	Mean	-	-	-	1327	-	-	-	104.5	105.1	104.8
	Std. Dev.	-	-	-	456	-	-	-	1.03	2.17	1.29
	$\overline{SPL}^x$	-	-	-	-	-	-	-	104.6	105.6	105.1

JAW CRUSHER OPERATOR — D = 13.5 cm

No.	Ear Muff	Comfort	Clamping Force (g wt) L.S.*	R.S.*	B.S.*	Attenuation (dBA) L.S.	R.S.	Ave.	L_{eq} (dBA) L.S.	R.S.	Ave.
1	A	◇	-	-	580	15	15	15	101.7	101.3	101.5
2	B	◆	580	330	910	4.7	13.8	11.29	97.4	100.9	99.15
3	C	◆	630	680	1310	9.8	10.8	10.33	100.4	103.6	102
4	D	◆	980	1080	2060	14.3	6.8	12	102.5	101.8	102.15
5	E	◈	-	-	1980	18.4	19.2	18.82	102.2	101.3	101.75
6	F	◈	-	-	1180	18	26.2	23.8	99.7	100.9	100.3
7	G	-	-	-	1180	-		-	-	-	-
8	H	-	-	-	1080	-		-	-	-	-
9	I	◆	680	830	1510	7.4	9.0	8.27	100.3	103.7	102
10	J	◇	-	-	1330	22.8	23.4	23.11	95.9	98.6	97.25
11	K	◈	-	-	880	17.8	13.4	16	100	103.4	101.7
Σ	Mean	-	-	-	1273	-	-	-	100	101.7	100.87
	Std. Dev.	-	-	-	447	-	-	-	2.18	1.65	1.68
	$\overline{SPL}^x$	-	-	-	-	-	-	-	100.44	101.98	101.28

Mine Standard in Use

NOTE: + Evaluation ◆ Satisfactory (1)
◈ Good (2)
◇ Very Good (3)

* L.S. - Left Side; R.S. - Right Side; B.S. - Both Sides

x Average $\overline{SPL} = 10 \log \frac{1}{n} (\text{antilog} \frac{SPL_1}{10} + \text{antilog} \frac{SPL_2}{10} + ... + \frac{SPL_n}{10})$

① Tested while mounted on helmet; 905 ERB Plastics, inc., Woodstock CA, 905.

② Tested while mounted on helmet; Classe C, CSA Standard Z 94.1.

③ Tested while mounted on helmet; Safety Supply Co., Rain Guard, Safe-T-Cap, CSA Standard Z 94.1.

④ Tested while mounted on helmet; Hard Boiled, E.D. Bollard Co., S.F., U.S.A.

satisfactory attenuations.

Jaw Crusher Operator: Generally speaking, ear muffs should be used where the ambient sound levels exceed 105 dBA. Below this value ear plugs give good protection. Because ear muffs are practical for intermittent noise (and because infection can result from the use of ear plugs), usually only ear muffs are used to protect from lower noise levels in all areas of mines. Test results from eight ear muffs show sufficient attenuation, 90 dBA and below (Table 11). Only ear muff No. 9 had a very low attenuation (8.3 dBA). Once again, extremely good attenuation was provided by three muffs: No. 5 (18.8 dBA), No. 6 (23.8 dBA) and No. 10 (23.1 dBA).

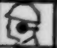
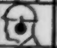
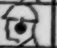
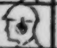
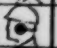
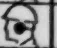
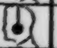
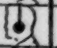
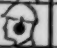
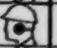
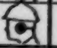
4.6. Clamping Force and Comfort

On the average, ear muffs have poor attenuation (15 dBA). The efficiency of an ear muff is determined by its clamping force and its fit over the ear. If the clamping force is decreased, attenuation also decreases. Clamping force will vary in each case because of different head sizes (Table 11). A good fit over the ear is an important factor for noise attenuation, and it is inter-related with comfort. From the tests performed it is evident that comfort and attenuation affect one another (Table 12).

Characteristically, ear muffs mounted on the hat with bands passing the head have different comfort evaluations and different attenuation results (Nos. 4, 5, 9 and 10). In all cases, hats cause these discrepancies. There are other numerous causes: poor mounting due to insufficient instructions,

TABLE 12

Summary of Comfort and Measured Attenuation, Approximate Attenuations and Theoretical Attenuation

No.	Ear Muff	Band	Comfort+				Noise Reduction - dBA																				
			Jumbo Operatr	Hydro Operatr	Crusher Operatr	Σ	Measured*				Approximate Methods												Theoretical Method			
							Jumbo Operatr	Hydro Operatr	Crusher Operatr	Σ/3	Jumbo Operator				Hydrofore Operator				Crusher Operator				Jumbo Operatr	Hydro Operatr	Crusher Operatr	Σ/3
											1+	2+	3+	Σ/3	1+	2+	3+	Σ/3	1+	2+	3+	Σ/3				
1	A		⬙	◆	◇	6	18.6	12.6	15	15.4	20.38	16.78	17.28	18.15	22.71	18.71	17.28	19.57	21.16	17.65	17.28	18.70	26.9	28.8	27.7	27.8
2	B		⬙	◇	◆	6	16.5	12	11.3	13.3	-	13.08	13.50	13.29	-	15.52	13.50	14.51	-	14.06	13.50	13.78	23.1	25.5	24.1	24.2
3	C		◆	◆	◆	3	11.5	8	10.3	9.9	-	17.73	18.35	18.04	-	19.56	18.35	18.95	-	18.54	18.35	18.44	27.8	29.6	28.6	28.7
4	D		⬙	◇	◆	6	13.6	10.5	12	12	-	18.20	18.87	18.53	-	19.90	18.87	19.38	-	19.02	18.87	18.94	28.2	29.9	29	29
5	E		⬙	◇	◇	7	25.7	25.3	18.8	23.3	21.95	19.22	19.85	20.34	23.21	20.89	19.85	21.32	22.97	20.45	19.85	21.09	29.4	30.9	30.4	30.2
6	F		◆	⬙	⬙	5	8.6	24.6	23.8	19	24.67	20.62	21.17	22.15	25.43	21.38	21.17	22.66	25.35	21.33	21.17	22.62	30.6	31.4	31.3	31.1
7	G		-	-	-	-	-	-	-	-	-	(25.07)	(25.66)	(25.36)	-	(27.04)	(25.66)	(26.35)	-	(25.91)	(25.66)	(25.78)	(34.6)	(36.3)	(35.4)	(35.4)
8	H		-	-	-	-	-	-	-	-	-	(25.07)	(25.66)	(25.36)	-	(27.04)	(25.66)	(26.35)	-	(25.91)	(25.66)	(25.78)	(34.6)	(36.3)	(35.4)	(35.4)
9	I		◆	⬙	◆	4	3.2	5.8	8.3	5.8	24.81	18.48	18.94	20.74	24.73	19.9	18.94	21.19	25	19.29	18.94	21.08	28.5	29.9	29.3	29.2
10	J		◇	⬙	◇	8	25	18.2	23.1	22.1	21.67	18.30	18.44	19.47	23.19	20.11	18.44	20.58	22.62	18.85	18.44	19.97	27.9	30.1	28.9	29
11	K		◆	◇	⬙	6	11.8	10	16	12.6	22.26	19.02	19.49	20.26	23.81	20.09	19.49	21.13	22.76	19.74	19.49	20.66	29	30.2	29.8	29.7
Σ-(7+8)	Arithmetic Mean						14.94	14.11	15.40	14.82	22.62	17.94	18.43	19.00	23.85	19.56	18.43	19.92	23.31	18.77	18.43	19.48	27.93	29.59	28.79	28.77
	Std. Dev.						7.38	7.03	5.55	5.74	1.76	2.11	2.14	2.53	1.04	1.69	2.14	2.33	1.58	2.07	2.14	2.53	2.10	1.70	2.04	1.95

Notes:

* In Mines,

+ Method.

+ Evaluation: ◆ Satisfactory (1)

⬙ Good (2)

◇ Very Good (3)

* Appendix A-3, Computer Program

Noise Surveys in Mines										
Measured at the Operator's Ears	Frequency (Hz)									dBA
	31.5	63	125	250	500	1000	2000	4000	8000	
Jumbo (Three Drills)	89	100	109	109	109	107	108.5	109.5	106	115.24
Drill Hydrofore	68	79	86	99	96	99	99	99	94	105.2
Jaw Crusher	89	94	94.5	94.5	94.5	94.5	94	97	88	101.64

Total noise estimated from the octave-band noise levels given in the first nine columns.

varying head dimensions and ear heights, improper fitting, interference by hair or eye-glasses, improper wearing of ear muffs, etc. Because of this the value of a measured attenuation in use does not equal the value obtained by approximate method for calculating noise reduction and factory attenuation (28) (29) (Table 12). Results of the factory noise reduction can be easily compared with EPA's* proposed labeling of hearing protection products (30).

Clamping force studies were made with eleven ear muffs (Table 13). The mean value is 1256 ± 77 (g wt) (Standard error is ± 77 (g wt)). In various references in the literature it can be found that a clamping force can vary between 500 and 1000 grams (31). Many manufacturers' catalogues contain no information about clamping forces. Only the Mark IV, MSA, specifications claim that the head pressure (clamping force) is 1191 (g wt) at 14.2 cm (32). According to the calculated mean, this would correspond to 1256 - 77 = 1179 (g wt) at 13.4 cm. The data in the literature differ from practical data. Manufacturers have increased clamping forces in their products thus creating discomfort for the wearer. They did this because they are well aware that too small a pressure results in the creation of air leaks.

4.7. Discussion

Assuming that ear muffs are excellent attenuators (which they are not), and that a miner is working under noise levels of 115 dBA (Jumbo-Three Drills), then he would have to wear his muffs 95 percent of the drilling time to lower his exposure to within the 85 or 90 dBA limit.

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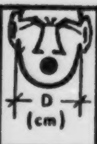
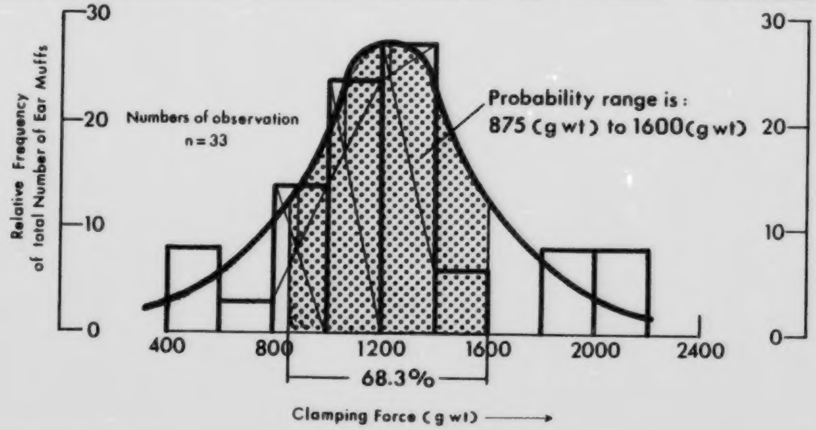
* The Environmental Protection Agency, U.S.A.

TABLE 13

Summary of Clamping Force Survey Data

Type of Equipment	 D (cm)	Clamping Force (gwt)		Mean	Std. Dev.	Number of Items					
						Clamping Force (g wt)					Σ
		Lower	Upper			400-800	800-1200	1200-1600	1600-2000	>2000	
Jumbo (3 Drills) Operator	12.8	430	1960	1168	443	2	4	3	2	-	11
Drill Hydrofore Operator	13.8	580	2110	1327	456	1	3	5	0	2	11
Jaw Crusher Operator	13.5	580	2060	1273	447	1	6	3	0	1	11
Average	13.4	430	2110	1256	440	4	13	11	2	3	33



Taking his muffs off for 12 minutes in a four hour drilling period would over-expose the miner to noise. Most hearing loss occurs in the first five years of exposure to noise (33). A man who has worked in noisy environments for 25 years gains little practical benefit from even the most powerful muffs (34). Of course, safety organizations in mines must be capable of performing the task of controlling attenuation of ear muffs.

Two types of safety organizations exist in Canadian mines. The first is in effect in smaller mines and safety is the specific responsibility of all management. Staff safety organizations are used at medium and large mines. The safety program is headed by supervisory personnel. They are not responsible for production and should not give orders to miners. It is considered that the foreman is the key to the entire accident prevention problem. He is in the best position to put safety into practice, and must become capable of doing so through experience and training. Miners must be induced to cooperate in the training.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Exposure to noise of sufficient intensity for long periods of time can produce detrimental changes in the inner ear and decrease the ability to hear. Noise pollution has been recognized as a hazardous problem in Canadian mines and mills. Mechanization in mines has resulted in higher noise levels. Persons operating machines that produce excessive noise, and miners in close proximity, are exposed to high noise levels. These miners are required unconsciously to make use of their decision - making abilities in determining the effects of noise on peripheral vision, the amount of muscle tension required to do the task, spatial positioning of the head, the processing of communicative information, and other aspects of performance. An analysis showed that Canada has made great efforts in the abatement of noise in mines. The high cost of fully implementing a 90 dBA noise standard, and to comply with the 85 dBA noise standard, requires that we develop very inexpensive and very effective methods in the battle against noise in mines.

The most important function of an ear muff is that it will attenuate noise while providing a comfortable fit. Manufacturers claim that ear muffs are shaped to fit all ears comfortably; this is not always the case. Some of the main problems encountered in ear muffs are caused by the ear cushion seal against the head and their functional design. In comfort tests it was demonstrated that ear muffs with large cushion areas were favoured (Tables 2 and 4).

The noise levels reaching the ears were calculated by a computer model for ear muffs fitted by either the octave-band or the sound level conversion method. The method provides an acceptable basis for selecting ear muffs in any industrial noise spectrum not dominated by intense pure tone or narrow-band energy components.

Methods using short measurements for the determination of a noise exposure index, and modes of control for good muff wearing, were developed in the Elliot Lake Laboratory. Tests in mines showed that only three ear muffs of all those examined have good attenuations (Table 6);

- No. 5, model E: (23.3 dBA)
- No. 6, model F: (19 dBA), and
- No. 10, model J: (22.1 dBA).

All three ear muffs are worn with the compression band passing behind the head. The No. 10 muff has a support strap which improves comfort and maintains a good fit during wear. Causes of poor attenuation are numerous: bad mounting of ear muffs on helmets, improper fitting, interference by hair and eyeglasses, improper wearing by miners, unsatisfactory enforcement by supervisory personnel, incomplete training of miners, etc.

Laboratory tests showed that a difference exists in attenuation between muffs, and a difference also exists in attenuation characteristics between factory (ANSI Z 24.22-1957) and laboratory tests. The best comparison resulted with No. 10, model J (pages 25 to 29). There was poor agreement in attenuations between laboratory tests and field tests.

Results of this research have indicated that none of the currently manufactured ear muffs tested in this study contain all of the characteristics desirable in an ideal unit.

Today, in Canadian mines, ear muffs are considered to be a part of safety equipment such as helmets, masks, safety glasses, gloves and safety boots.

5.2. Recommendations

1. The results suggest that obligatory tests, which were developed in the Elliot Lake Laboratory for ear muff attenuation, should be introduced.

These tests require only two dosimeters and a stop watch. Dosimeters have the small sized microphones and provide very accurate short time readings of the noise exposure index. Also, a pocket-sized computer designed for sound amplitude analysis should be utilized (dBA, L_{eq}, L_{max} and time duration of the sampling period). Portable instruments that monitor the real attenuation of ear protectors while worn at the work station exist on the market. These instruments are impractical in mines because they slow down the normal work pace, thus changing the noise level.

2. Because of unsatisfactory ear muff attenuation in working conditions, it should be a mandatory requirement that workers wear both ear muffs and ear plugs if the noise level is higher than 105 dBA (various references in the literature recommend 110 dBA).
3. It is recommended that miners use support straps to maintain effective attenuation and positioning of ear muffs which are worn behind the head. To convince the employee of the importance of a hearing conservation program requires planning, educational effort, persistent control and assistance.
4. Foremen must be capable, through experience and training, to help and control miners in their task of properly wearing ear muffs.
5. Introduce the program to new miners at the start of employment.
6. When purchasing ear muffs, practical attenuation results should be taken into account, because the greatest noise reduction is not always given by ear muffs which have the best attenuation characteristics in

the laboratory.

7. Constant contact must be maintained with manufacturers to improve design, maintenance, and servicing of ear muffs.

6. ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Mines Accident Prevention Association of Ontario for providing a selection of ear muffs for this project, and for approval of this publication. He also expresses his appreciation to G. Stenning, Project Manager at Denison Mines Limited, for approval of this publication.

He acknowledges E.D. Dainty, Project Leader, CEAL; Dr. R. Tervo and G. Knight, all of whom were helpful in many ways. Grateful acknowledgement is given to A. Webster who transcribed and completed the tables from the raw data. He acknowledges the contribution of R. Regan for his assistance in the laboratory work and H. Poliquin for his assistance in field work.

7. REFERENCES

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VOL. 2 Report 8

80-59 M. Savich

Practical problems of hearing protector use in Canadian mines

1980

Published in Personal Hearing Protection in Industry.

Edited by P.W. Alberti

New York, Raven Press pp 403-425; 1982

PROBLÈMES PRATIQUES POSÉS PAR LES SYSTÈMES DE PROTECTION DE L'OUÏE UTILISÉS DANS LES MINES CANADIENNES

par

M. Savich

Les mineurs sont exposés à des niveaux de bruit élevés et peuvent devenir temporairement ou définitivement sourds. En raison de la fréquence élevée des cas de perte d'audition, des mesures importantes ont été prises pour introduire des programmes de préservation de l'ouïe dans les mines canadiennes. Les dangers associés au bruit et aux vibrations en milieu de travail doivent être maintenus entre certaines limites grâce à

a) des mesures techniques
b) des mesures administratives supplémentaires lorsque les mesures techniques ne suffisent pas pour apporter une protection suffisante.

Il est souvent impossible de réduire raisonnablement le niveau de bruit à la source ou en utilisant des matériaux spéciaux et des barrières acoustiques. Dans ce cas, il convient d'envisager une forme quelconque de protège-oreilles pour les travailleurs exposés au bruit. Les principaux avantages de l'emploi de protège-oreilles dans les mines canadiennes sont les suivants :

1. réduction des risques de perte d'audition
2. conditions de travail plus agréables.

Dans les mines canadiennes, cinquante pour cent des travailleurs exposés au bruit utilisent des casques antibruit, quarante pour cent des bouchons protecteurs et trois pour cent des casques antibruit avec des bouchons protecteurs. Les sept pour cent restants n'utilisent pas d'appareil protecteur ou alors de façon temporaire. Les bouchons protecteurs en mousse sont les seuls utilisés couramment dans les mines canadiennes. Par contre, un grand nombre de casques antibruit différents sont en service. Nous avons donc mené une étude visant à évaluer l'efficacité des casques antibruit dans des conditions de travail.

L'étude comportait trois volets : méthodes utilisées à l'usine, essais en laboratoire et performance dans les mines souterraines. Les résultats ont ensuite été comparés. Tout au long de cette étude, nous avons utilisé des méthodes et du matériel simples.

Les systèmes de protection de l'ouïe doivent satisfaire les exigences suivantes :

1. Permettre une grande atténuation du bruit ambiant. Les meilleurs systèmes n'offrent pas une atténuation supérieure à 25-30 dB et l'atténuation théorique est limitée à enivron 50 dB car le bruit peut contourner le dispositif de protection par captage et par conduction osseuse. Utilisés seuls, les bouchons protecteurs permettent une plus grande atténuation à basse fréquence que les casques antibruit. L'atténuation est plus grande si le travailleur porte à la fois les bouchons protecteurs et le casque antibruit. Dans ce cas, l'atténuation est inférieure à la somme des atténuations individuelles, phénomène encore inexpliqué.

2. Être confortables. Un dispositif de protection de l'ouïe inconfortable devient intolérable après un usage prolongé.

3. Ne pas provoquer d'effets secondaires, tels des problèmes cutanés.

Personal Hearing Protection in Industry, edited by P. W. Alberti.
Raven Press, New York ©

25 PRACTICAL PROBLEMS OF HEARING PROTECTOR USE IN CANADIAN MINES

M. Savich

INTRODUCTION

Miners are exposed to high levels of noise and become temporarily or permanently deafened. Because of the high incidence of hearing loss, major steps have been taken to introduce hearing conservation programmes into Canadian Mines. The occupational hazards in the working environment due to noise and vibration should be kept within limits[1] by:

a) technical measures
b) supplementary administrative measures, where the technical measures alone do not provide sufficient protection.

Often the noise level cannot be reasonably reduced at its source or by the use of acoustical materials and noise barriers. In such cases, some form of ear protection should be considered for noise exposed workmen. The major benefit of noise control by means of hearing protector usage in Canadian mines are as follows:

1. reduced risk of hearing loss
2. more pleasant working conditions.

In Canadian mines, fifty percent of noise exposed workers use ear muffs, forty percent ear plugs and three percent ear muffs and ear plugs. The remaining seven percent do not use ear protection equipment, or use it temporarily. As foam ear plugs are the only ones in general use in Canadian mines, but many different types of muffs are in service, a research study was conducted to investigate the efficiency of ear muffs under working conditions.

Results obtained under the three general headings, factory procedures, laboratory tests and underground performance were computed and compared. Simple methods and simple equipment were used during these studies.

Ear protectors must comply with the following basic requirements:

1. Achieve high attenuation of ambient noise. The best ear protectors do not attenuate more than 25 to 30 dB and theoretical attenuation is limited to about 50 dB because noise can by-pass the ear-protector by pick-up and by bone conduction[2]. Used by themselves, ear plugs provide more attenuation at low frequencies than do ear muffs. Ear plugs and ear muffs can be worn at the same time to provide greater attenuation. The attenuation offered by the combination is less than the sum of the individual attenuations, a phenomenon which has not yet been explained.
2. Be comfortable. An uncomfortable ear protector becomes intolerable after prolonged use.
3. Avoid harmful side effects; such as skin disorders.

TECHNICAL AND ATTENUATION DATA FOR EAR MUFFS

Technical and attenuation data on ear muffs is given in Tables 1 and 2. Cushion areas, cup volumes and weight vary visibly. Cups are covered by foam on the inside for two reasons: to increase attenuation because uncovered cups permit entry of sound; and to prevent the formation of standing waves. Several attempts have been made in the laboratory to increase attenuation using metal ear muffs, adding one or more Helmholtz resonators, or by using soft hollow cushions filled with wax[3]. An older example is the NRC type ear muff developed at the National Research Council, Ottawa, by Shaw and Thiessen[4]. This device when properly fitted may be worn for many hours without discomfort[5]. Constant technical progress in ear muff design is evident by all manufacturers.

Comfort: One of the Main Requirements of Ear Muffs

The comfort provided by ear muffs depends both upon the ear cushion seal against the head and the overall design of the muff. The pressure of ear cushion seals against the head is a direct consequence of the clamping

Table I Characteristics of Muffs Tested

No.	Ear Muff	Filled Cushion	Cross-sectional Dimensions (cm)						Area of cushion (cm^2)	Volume of cup (cm^2)	Weight (g)					Total Weight of Ear Muff (g)
			A	B	C	D	E	F			Cup	Cushion	Foam	Fibre-Glass	wt	
1	A	Foam	9.7	9.7	6.5	4.3	1.1	4.2	48.0	180	49.86	13.67	7.61	-	71.14	165
2	B	Air	9.5	9.5	6.5	4.2	0.8	4.8	40.0	159	73.45	11.44	3.90	-	88.79	284
3	C	Foam	10.7	8.0	6.7	4.0	1.0	3.6	35.6	117	51.13	5.79	0.59	2.46	59.97	188
4	F	Foam	10.5	8.0	6.8	4.1	0.9	3.8	28.5	131	45.30	4.49	1.11	-	50.90	182
5	E	Foam	10.6	8.0	6.8	4.2	1.0	3.8	28.0	131	42.80	4.43	1.27	-	48.50	151
6	F	Foam	9.8	8.3	6.5	3.9	1.0	4.5	43.1	158	63.40	10.47	8.07	-	81.94	291
7	G	Fluid	11.0	8.3	6.3	3.6	0.7	4.4	38.7	167	68.64	56.29	2.90	-	127.83	335
8	H	Foam	11.0	8.3	6.4	3.7	0.8	4.4	42.5	164	57.02	19.87	4.91	-	81.80	274
9	I	Foam	9.4	6.9	6.9	4.6	1.0	4.4	26.7	171	73.94	8.92	3.21	-	86.07	278
10	J	Foam	9.4	6.9	6.9	4.6	0.9	4.4	24.5	171	76.26	9.05	3.34	-	88.65	275
11	K	Foam	11.0	8.2	6.5	4.2	1.0	3.6	42.2	141	52.92	15.92	2.48	-	71.32	295
Arithmetic Mean			10.24	8.2	6.62	4.13	0.93	4.17	36.16	153.6	59.50	14.58	3.58	2.46	80.12	248
Std. Dev.			0.68	0.86	0.21	0.32	0.12	0.4	7.98	20.4	12.16	14.61	2.46	-	29.25	60.5

force, adjustment, softness and weight.

1. Clamping force (Head force): The clamping force is the force exerted by an ear muff on the skin and it is the most important element of discomfort. The clamping force against the sides of the head varies between 500 and 1000 g wt[6]. Pressure limits have not yet been important aspect. The clamping force varies and depends on the bizygomatic diameter of the head.

2. Adjustment: Ear Muff adjustment is necessary to adjust to the shape and dimensions of a worker's head. To fulfil the criterion of a tight fit, the muffs should have the capability of moving the support up and down so as to be parallel with the wearer's ears. To make allowances for each person's unique head shape, they should also be rotational on a pivot point. An effective seal inside the cup prevents acoustical leakage around the bearing surface. A poor linkage between the helmet and the cups hinders clamping force and comfort. Poor mounting and asymmetry of ear muffs is caused by two things; inadequate data for hole locations on helmets and the poor mounting of ear muffs on helmets in mines.

A good solution is to use separate ear muffs with a spring worn behind the head (back-band with strap) and a support strap in conjunction with a safety helmet. This head-strap is adjustable over the head to avoid discomfort caused by the pull of gravity on the ear cups. It also helps maintain the ear cups in position.

3. Softness: Softness is a prime consideration for ear cushions. Apart from the vital aspect of comfort, an effective noise seal depends upon the cushion being soft enough to assume the contours of the head and to fit snugly around the frames of glasses or eyeglass adapters. New materials for cushion seals perform the function of adapters. The No. 3 ear muff, model C, has foam filled cushions with covering material of soft, supple plastic film. Some ear cups have special cushions with replaceable snap in/out foam over a liquid sealing ring to afford even pressure without gaps, even when wearing eye glasses.

Table 2 Attenuation Characteristics (in dB)* and Technical Data of Ear Muffs Acquired for Testing

				Frequency in Hertz								
No.	Ear Muff	Band	Characteristic	125	250	500	1k	2k	3k	4k	6k	8k
1	A	B	Measured	9.70	16.10	24.90	33.90	34.10	36.00	41.00	33.80	31.50
			Std. Dev.	3.20	2.50	2.80	5.10	2.90	5.60	5.70	6.60	5.90
2	B	H	Measured	5.00	13.00	22.00	31.00	31.00	41.00	36.00	28.00	21.00
			Std. Dev.	-	-	-	-	-	-	-	-	-
3	C	H	Measured	10.00	16.00	30.00	34.00	37.00	41.00	45.00	39.00	34.00
			Std. Dev.	-	-	-	-	-	-	-	-	-
4	D	H	Measured	11.50	16.50	26.50	36.50	38.00	38.50	44.50	39.50	-
			Std. Dev.	-	-	-	-	-	-	-	-	-
5	E	B	Measured	13.40	17.30	28.60	41.80	40.70	45.20	42.70	32.60	29.30
			Std. Dev.	3.30	3.90	3.00	3.40	5.60	4.60	5.30	4.10	4.70
6	F	B	Measured	17.00	18.00	29.00	36.00	38.00	44.00	44.00	43.00	43.00
			Std. Dev.	2.60	2.60	3.10	3.20	4.10	7.20	4.60	4.70	5.70
7	G	T	Measured	18.00	23.00	33.00	44.00	44.00	47.00	45.00	42.00	39.00
			Std. Dev.	-	-	-	-	-	-	-	-	-
8	H	T	Measured	18.00	23.00	33.00	44.00	44.00	47.00	45.00	42.00	39.00
			Std. Dev.	-	-	-	-	-	-	-	-	-
9	I	H	Measured	12.00	17.00	30.00	35.00	35.00	36.00	37.00	32.00	30.00
			Std. Dev.	2.50	3.00	4.60	5.60	4.50	4.30	4.20	4.10	2.90
10	J	B	Measured	10.00	17.00	28.00	37.00	36.00	44.00	39.00	32.00	30.00
			Std. Dev.	2.00	2.60	4.30	5.40	4.50	5.60	3.80	5.40	4.90
11	K	B	Measured	15.00	17.00	26.00	43.00	36.00	38.00	38.00	33.00	34.00
			Std. Dev.	5.20	3.90	8.80	3.60	4.90	6.60	6.80	1.30	5.30
	Arithmetic Mean of all Ear Muffs			12.16	17.09	27.80	37.22	36.98	41.07	41.22	35.49	33.53
	Std. Dev.			3.86	2.47	3.09	4.31	3.58	3.90	3.49	5.00	7.36

B: Behind Head; H: Attached to hard hat; T: Band on top of head

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* Attenuation characteristic measured in accordance with American National Standard Specification Z.24.22-1957 (from Factory Data).

4. Weight: The weight of ear muffs greatly affects comfort because the force of gravity adds to the irritants already present. The total weight of a pair of muffs varies between 151 g and 335 g (Table 1). For comfort the weight of an ear muff must be limited to approximately 200 grams[7].

Table 3: Comfort Test of Ear Muffs using industrial elimination

	# of Subject	2	5	10	15	16	17	19	21	22	23	24	25	26	27	
#	Ear muff/ age	24	29	30	40	42	42	46	49	52	52	55	57	59	60	
1	A	X	Y	X	X	X	X	Y	Y	O	Y	X	Y	O	Y	40
2	B	Y	O	O	O	O	Y	Y	X	O	Y	O	Y	Y	O	83
3	C	X	Y	Y	X	Y	Y	Y	X	X	X	X	X	Y	Y	40
4	D	O	O	Y	Y	O	X	X	Y	X	Y	O	Y	O	X	43
5	E	X	O	X	X	X	X	X	X	X	Y	Y	Y	X	X	38
6	F	O	O	X	Y	Y	X	X	X	X	O	Y	Y	Y	Y	56
7	G	X	X	X	X	Y	Y	Y	Y	Y	O	O	Y	Y	Y	54
8	H	X	X	X	X	Y	Y	Y	Y	Y	O	O	Y	Y	Y	54
9	I	O	X	X	X	O	Y	Y	X	Y	Y	O	Y	O	Y	67
10	J	Y	O	X	X	Y	X	Y	Y	O	Y	O	X	Y	X	56
11	K	Y	X	X	X	Y	X	O	Y	Y	O	X	Y	O	Y	56
		43	56	24	27	49	22	33	25	33	52	56	34	62	36	562

Note:

Evaluation
X Satisfactory (1)
Y Good (2)
O Very Good (3)

83 Maximum

Industrial elimination

Tests of Comfort

Ear muffs must be sufficiently comfortable to be worn for long periods of time, perhaps up to 8 or 10 hours a day. The comfort of ear muffs can be quantified, although, such a test has yet to be generally accepted. Women were eliminated from the tests because so few are employed in mining industries[8]. A subjective evaluation was undertaken (Table 3). Subjects were asked to classify comfort as 1) satisfactory; 2) good; and 3) very good. The experiment was designed so that the differences among age (rows) and qualitative evaluation (columns) represented a major source of variation. Such an arrangement is known as a Latin square[9]. We used the method of industrial elimination in the parallel entries. Full details are given elsewhere[10].

The data obtained from fourteen reliable subjects (mean age is 45.5 ± 3.09 years) showed a significant difference between muffs. In the analysis, larger cushion areas (Tables I and 3) seemed to be a significant feature in determining comfort.

Head Size Survey

The variety of size, shape, and contour of the human head poses a difficult problem for manufacturers of ear muffs. The major reason for making the bizygomatic diameter survey was to evaluate the clamping force required in ear muff design. A measurement of maximum distance between the bony structures (zygomatic arches) forward of the ears was carried out on 27 men. Statistical analysis of the samples showed that small, but significant differences existed between ethnic groups (Table 4). Subjects came from the United Kingdom, Continental Europe and Asia, and were classified accordingly. The number of people of non-Caucasian origin is large, 26 percent of the population.

In the literature, the volume of bizygomatic diameter data which has been published of Caucasian ethnic origin is relatively small. Comparison of results from Table 4, with other surveys from the literature, showed minor differences of no practical importance[11,12,13,14]. Bizygomatic diameter surveys indicate that differences in head size may be sufficient to affect clamping force in some instances and give low attenuation or discomfort.

The ANSI S3.19-1974 standard recommends separating ear cups 14.35 cm. (medium head width), when measuring the clamping force.

Table 4 Bizygomatic Diameter Surveys

No.	Population	No. of persons	Means	
			D (cm)	Age (years)
1	Caucasian	20	14.47 ± 0.17	38.70 ± 2.55
2	Non-Caucasian	7	14.13 ± 0.26	43.29 ± 4.43
3	Canadian+	16	14.43 ± 0.16	38.94 ± 3.07
4	Non-Canadian+	11	14.23 ± 0.26	41.27 ± 3.18
5	U.K.++	13	14.17 ± 0.13	37.38 ± 2.90
6	Cont. Europe++	10	14.17 ± 0.28	45.20 ± 4.13
7	Slavic++	5	15.00 ± 0.50	44.80 ± 4.55
8	Asia+++	7	14.13 ± 0.26	43.29 ± 4.43
9	Age 19-39	13	14.05 ± 0.15	30.00 ± 1.48
10	Age 40-60	14	14.44 ± 0.19	49.07 ± 1.85
	Canadian	27	14.35 ± 0.14	39.89 ± 2.21

+ 16 Canadian-born versus 11 non-Canadian-born

++ U.K. origin, Cont. Europe origin, Slavic origin in Cont. Europe.

+++ Including Hungary and Finland.

LABORATORY TESTS OF EAR MUFFS

Measurements of ear muff attenuations have been made using two methods:

1. Psychophysical method using human heads by static range-of-movement:
   a) Movement of the joint of the neck in normal position. Subject used glasses and adapters.
   b) Movement of the joint of the neck, flexion, (dorsal and ventral) and neck rotation (right and left). Subject used glasses.
2. Physical method using apparatus for determining the efficiency of cup cushions.

These tests were made to provide performance data for eleven models of ear muffs under testing procedures established in the Elliot Lake

Laboratory (Table I).

Psychophysical Method

The ear muff attenuations was measured as a transmission loss, the difference between the noise level outside the ear muff (measured 0.1 m from the side of the head) and that inside the ear muff[15]. This method can be expected to give slightly different results than the American Standards Association's standard method[16,17].

Equipment The test signals were produced with a Bruel and Kjaer random noise generator, type 1402. The high powered loudspeaker was placed 1 m from the subject. Microphones were suspended at the subject's ear: one under the cup and one over the cup, 1.3 m above the floor, and located in the centre of the room.

The basic system for measuring soundpressure levels with a sound level meter consists of the following:

1. Transducer: a) A 1 in., type 4145, B and K microphone was used over the cup. b) A 1/4 in., type 4135, B and K microphone was used under the cup.
2. Preamplifier: a) A type 2619, B and K preamplifier was used over the cup. b) A type 2615, B and K preamplifier was used under the cup.
3. Sound level meter: a) Impulse precision sound level meter, type 2209, B and K. An octave filter, type 1613, B and K, was connected to an impulse precision sound level meter. b) A precision sound level meter, type 2203, B and K. An octave filter, type 1613, B and K, was connected to a prescision sound level meter.

The calibrator was a pistonphone, type 4220, B and K, and the sound level calibrator was a type 4230, B and K.

Subject Selection and Test Room

Two subjects for these tests were selected from the laboratory personnel. Subject 1 (age 35) with long hair, had a mezzocephalic head with a bizygomatic diameter of 13.6 (significantly smaller than average), and subject 2 (age 54) short haired, had a brachycephalic head with a bizygomatic diameter of 16.5 (significantly larger than average).

The tests were conducted in an empty semi-reverberant room held at constant temperature, 4.25 m long, 4 m wide and 2.5 m high. The walls, ceiling and floor were constructed of wood and there was one window and one door in the room. Maximum ambient noise levels at the position of the subject were 35 dBA.

Test Procedure:
Each of the subjects was taught the correct fitting procedures for the eleven models. The device was first positioned by the experimenter and then adjusted by the subject for a final orientation for each test.

Attenuation Measurements: Measurements of variation in sound pressure levels for a constant test signal level were made on both the left and right sides of the head. The ear muff attenuation was determined at the following frequencies: 125, 250, 1000, 2000, 4000 and 8000 Hz and at the dBA weighting network using the factory attenuations given in Table 2. Average noise levels of the test signals was calculated, and the noise reduction ratings for eleven ear muffs were determined. There were 7 tests on both ears of two subjects, thus 28 sets of measurements in all. One ear muff had 4 extra tests.

Effect of Glasses and Adapters on Attenuation of Ear Muffs
During this test the listener's neck joint was in normal position. The raw data of the attenuation tests of ear muffs are summarized in a graph (with frequency in hertz). Total noise was estimated from the octave-band noise levels. Approximate agreement with the total noise measured indicates a reasonably constant condition during the period of measurement.

Measurements of ear muff attenuations were made in the current series of tests with: (a) ear muffs; (b) ear muffs and glasses; and (c) ear muffs, glasses and adapter. Muffs/ eyeglass adapters were specially designed for people wearing glasses in conjunction with hearing protectors.

The detailed results are presented elsewhere[10], but summarized, show the following:

1. Attenuation for subject 2 with large head and short hair was higher than attenuation for subject 1 with small head and long hair, except in four measurements.

Table 5 Comparison of manufacturers' data and field test performance of muffs

Ear Muff No.	1	2	3	4	5	6	7	8	9	10	11
Noise Reduction (dBA)$^{+}$	34.2	31.1	36.8	37.5	39.9	38.0	43.6	43.6	35.0	36.3	36.4
Attenuation* (dBA)	27.3	29.7	30.0	30.0	31.5	27.0	29.9	34.8	31.6	32.1	27.3
Difference (dBA)	6.9	1.4	6.8	7.6	8.4	11.0	13.7	8.8	3.4	4.2	9.1
Order of Performance**	5	1	4	6	7	10	11	8	2	3	9

NOTE: + from manufacturers literature

* from Table 6

** 1 = best; 11 = worst

Only No. 2 ear muff came close to the factory attenuation value.
The largest attenuation was displayed by ear muff No. 8.

2. Ear muffs No. 2, No. 5, and No. 8 had almost equal attenuations for both subjects.
3. The largest attenuation difference for both subjects occurred with the No. 6 ear muff, apparently due to subject 1's long hair. Substantial differences were also found with ear muffs No. 2, 7 9 and 10.
4. With the use of glasses and their adapters, attenuation decreased. The adapters are not effective sound barriers.
5. Most ear muffs show a lower attenuation than those given by the factory specification as shown in Table 5.

Effect of Movement of Joint of the Neck, Flexion and Neck Rotation on Attenuation of Ear Muffs

This test was similar to the previous one. The object of this test was to see the stability of ear muffs on heads in motion, and to measure air leaks when wearing glasses. The left hemisphere was tested with glasses and the right hemisphere was tested without them. The detailed results are presented elsewhere, but in summary, they show:

1. There are no great differences in attenuation when the neck moves;
2. The test performed on subject 1 (D = 13.6 cm) showed that the amount of hair trapped between the ear muff cushion and the head had a significant effect on ear muff attenuation.
3. The largest difference in attenuation between two subjects is once again with the No. 6 ear muff (left side 16 dBA, and right side 18.06 dBA).
4. The greatest attenuation occurred with the No. 10 ear muff on both subjects (34.21 dBA).
5. On the average, with both subjects, glasses decreased attenuation by 1.42 dBA.

Cushion Seals and Clamping Force

Manufacturers' specified attenuations were attained only on ear muffs No. 2 and No. 10 when worn on a large head with short hair, subject 2. The hair length had the largest effect on ear muff attenuation even if the ear muff has cushion seals that retain softness. With the use of glasses and adapters attenuation decreased substantially on small as well as large heads. Eye-glass adapters do not have the characteristics attributed to them in the literature[18]. The cause is simple: new materials for cushion seals perform the function of adapters.

Attenuation mainly depends upon two factors: clamping force and cushion seals. An increase in clamping force results in an increased attenuation.

PHYSICAL METHOD

Ear muff attenuation was measured as the difference between the outputs of the microphone uncovered and the cup covered microphone. For this test the apparatus to determine the efficiency of cup cushions under different clamping forces was made in the Elliot Lake Laboratory.

Instrumentation

The sound field of a pure tone at 500 Hz, 1000 Hz, 3000 Hz and 8000 Hz, was generated by a Hewlett-Packard test oscillator, model 650A. A loudspeaker was placed 1 m from the centre of the apparatus taken in horizontal and vertical directions. The microphones, preamplifier and sound level meter were as described earlier.

Apparatus Full details of the apparatus are given elsewhere[10]. Accoustical isolation of the apparatus was greater than 60 dB in any test frequency band in the range of interest.

Test Procedure

The ear cup was spread and placed on the plane plexiglass surface. A steelyard's rubber pin was pressed against the ear cup and a clamping force was selected. Loss of attenuation by an ear cup under a constant clamping force and different test signal level was examined.

Ear Muff Attenuation

The algebraic difference in sound pressure levels, in the dBA weighting network, at each test frequency signal, with and without the ear cup in place on the plexiglass, is considered to be the attenuation of the device. For a discussion of results, the clamping force at 450 g wt for one cup was used as a basic level (ANSI S 3.19-1974).

The ear muffs could be divided into three main groups:

Group	Ear Muff	Minimum Force (g wt)	Attenuation Behaviour
1	No. 4, No. 5, No. 8 No. 9, and No. 10	150 to 350	Steady at all frequencies and clamping forces above min.
2	No. 1, No. 3, and No. 6	350 to 550	Steady at some frequencies and clamping forces
3	No. 2, No. 7, and No. 11	550	Variable at all frequencies and clamping forces

In general, the attenuation values of ear cups are dependent upon two factors:

1. Clamping (head band) force (g wt), and
2. Design of the ear cup cushion.

Both factors were taken into consideration in this test. It was evident that attenuation is a function of size of air paths as shown by poor contact. An air path causes different losses of attenuation at various frequency test signals as well as different losses among the various ear muffs.

A greater attenuation is obtained when an ear cup is exposed to horizontal sound, than when it is exposed to vertical sound. According to acoustical laws, the opposite should be expected. Shaw came to the same conclusion and this phenomenon is yet to be explained[19].

This test explained the following:

1. Ear muffs with a small cushion area start serving their purpose more quickly because the force per square centimeter is larger;
2. A clamping force larger than 900 g wt, in the first and second groups, does not cause an increase in attenuation;
3. Attenuation characteristics (ANSI Z 24.22-1957) of ear muffs

show a correlation with physical tests. They cannot be completely compared because their values differ, dB versus dBA.

Based on the extensive literature and the physical tests performed, the apparatus for determining the efficiency of cup cushions can be used effectively to apply theory in the design of ear muffs.

EAR MUFF ATTENUATION TESTS IN MINES

A study was undertaken to measure ear muff attenuation in mines. A series of nine ear muffs was tested under uniform conditions in mines.

Objective of the Study

The only certain means for evaluating the efficiency of the hearing protection program, equipment, training and supervision, is to measure, periodically, the hearing thresholds of all miners exposed to noise[20]. However, this method does not detect problems until some hearing loss has occurred.

Because of this a new method, the "Noise Dosimeter Vest", has been developed in the Elliot Lake Laboratory to provide an assessment of attenuation efficiencies of ear muffs in use. It is fully described elsewhere[10].

Experimental Method

The Noise Dosimeter Vest provides a technical solution for the determination of the noise exposure index and the attenuation of ear muffs. It does so under the most difficult working conditions (i.e., single platform (giraffe), the load-haul-dump (LHD) vehicle, etc.). These tests require only two dosimeters and a stop watch. The dosimeters have small microphones and provide accurate short time readings of the noise exposure index. A pocket-sized calculator designed for sound amplitude analysis is also necessary (dBA, L_{eq}, L_{max} and time duration of the sampling period).

The surveyor must measure the distance between the bony structures just forward of the ears (bizygomatic diameter) using an outside caliper. On the basis of bizygomatic diameter measurements, the clamping force can be evaluated. An apparatus was designed in the Elliot Lake Laboratory for the immediate measurement of clamping force at the mines. Evaluations are done on the spot and the worker is immediately informed about the noise exposure index level and ear muff attenuation data. If the attenuation is unsatisfactory, the cause should be investigated.

Participants

In this study one man at each of three working sites was chosen:

1. Jumbo (Three Drills) operator
2. Drill Hydrofore operator
3. Jaw Crusher operator

Of particular importance were the following items:

- the miner is informed of the test's objective.
- the miner is asked to adjust his own ear muffs to his particular liking, and to make qualitative evaluations of comfort before and after the test.
- if a miner wishes to withdraw at any time and for any reason, he may do so.

It was explained that all testing would be conducted under the full support of miners and supervisory personnel.

Results

The results of the study indicate poor attenuation of ear muffs in underground mining conditions. As a result of analyzing the data obtained, three major findings are presented below.

1. Jumbo (Three Drills) Operator: While working, the jumbo operator used only ear plugs. The miner was of the opinion that his ear muffs were inefficient and wore them only because regulations required it. The ear muff was No. 6, model F, with hat mounting, that did not properly cover the ears, and which provided a mean attenuation of only 8.6 dB.

The noise levels are high (115 dBA) and that the ear muffs supplied do not offer adequate protection. For all ear muffs, one of the factors contributing to the low attenuation found was this man's extremely small head size. The ear muffs with adequate attenuation were Nos. 1, 2, 5 and 10. The jumbo operator judged ear muffs which are worn behind the head (Nos. 6 and 11) to be uncomfortable.

2. Hydrofore Drill Operator: Hydraulic drills are used increasingly on jumbo machines, replacing the heavy pneumatic rock drills (21). A hydrofore drill (hydraulic-electric fan) has no air exhaust noise and thus produces low noise levels at low frequencies. Because the attenuation of ear muffs is better at high frequencies, it should be expected that their efficiency would be very high. Test results demonstrate that good attenuations were obtained by ear muffs Nos. 5, 6 and 10 (25, 25 and 18 dB, respectively) with band passing behind the head. The other ear muffs did not provide satisfactory attenuations.

3. Jaw Crusher Operator: Generally speaking, ear muffs should be used where the ambient sound levels exceed 105 dBA. Below this value, ear plugs give good protection. Because ear muffs are practical for intermittent noise (and because infection can result from the use of ear plugs), usually only ear muffs are used to protect from lower noise levels in all areas of mines.

Test results from eight ear muffs show sufficient attenuation, to 90 dBA and below. Only ear muff No. 9 had a very low attenuation (8.3 dBA). Once again, extremely good attenuation was provided by three muffs: No. 5 (18.8 dBA), No. 6 (23.8 dBA) and No. 10 (23.1 dBA). The full results are published elsewhere (10).

Clamping Force and Comfort

On the average, ear muffs have poor attenuation (15 dBA). The efficiency of an ear muff is determined by its clamping force and its fit over the ear. If the clamping force is decreased, attenuation also decreases. Clamping force will vary in each case because of different head sizes. A good fit over the ear is an important factor for noise attenuation, and it is inter-related with comfort. From the tests performed it is evident that comfort and attenuation affect one another.

Characteristically, ear muffs mounted on the hat have different comfort evaluations and different attenuation results. In all cases, hats cause these discrepancies. There are numerous other causes: poor mounting due to insufficient instructions, varying head dimensions and ear heights, improper fitting, interference by hair or eye-glasses, improper wearing of ear muffs, etc. Because of this the value of a measured attenuation in use does not equal the value obtained by an approximate method for calculating noise reduction and factory attenuation[22,23]. Results of the factory noise reduction can be easily compared with EPA's (The Environmental Protection Agency, U.S.A.) proposed labelling of hearing protection products[24].

Clamping force studies were made with eleven ear muffs. The mean value was 1256 ± 77 (g wt) (Standard error is ± 77 (g wt)). In various references in the literature it can be found that a clamping force can vary between 500 and 1000 grams (6). Many manufacturers' catalogues contain no information about clamping forces. Only the Mark IV, MSA, specifications claim that the head pressure (clamping force) is 1191 (g wt) at 14.2 cm (25). According to the calculated mean, this would correspond to 1256 - 77 = 1179 (g wt) at 13.4 cm. The data in the literature differ from practical data. Manufacturers have increased clamping forces in their products thus creating discomfort for the wearer. They did this because they are well aware that too small a pressure results in the creation of air leaks.

Discussion

To verify the value of the tests and poor ear muff attenuation, ten tests were made on the No. 4 ear muff - D, which is used extensively in Canadian mines. Test results are shown in Table 6.

To find the reason for the poor attenuation, we used the same ear muff on

Table 6 Attenuation of ear muff 'D' in a local Elliot Lake mine

No. / Occupation	Ear Muff	Bizygo-matic Daim.	Equivalent Continuous Sound Level - L_{eqs} (dBA)						Average Attenuation (dBA)	Remarks
			Left Muff			Right Muff				
			Over	Under	Diff.	Over	Under	Diff.		
1 Jackleg (Driller)	D	14.70	114.60	98.2	16.4	114.9	105.00	9.90	13.15	Long hair
2 Jackleg (Driller)	D	14.00	111.80	93.20	18.60	112.70	94.60	18.10	18.35	Ideal condition
3 Jackleg (Helper)	D	13.80	112.60	108.00	4.60	114.30	98.80	15.50	10.05	Long hair
4 Rock Bolter (Helper)	D	13.60	114.60	106.20	8.40	115.20	104.90	10.30	9.35	
5 Slusherman	D	13.70	93.60	80.40	13.20	94.40	86.10	8.30	10.75	Lack spring pressure
6 Slusherman	D	14.00	96.80	80.00	16.80	97.50	80.00	17.50	17.50	
7 JC800 Scooptram	D	14.20	102.00	89.50	12.50	101.00	91.40	9.60	11.05	New liner
8 ST8 Scooptram	D	13.30	101.7	91.6	10.10	101.50	89.8	11.70	10.90	
Mean		13.91	105.96	93.39	12.58	106.44	93.83	12.61	12.59	
Std. Dev.		0.42	8.43	10.47	4.73	8.69	8.83	3.85	3.38	
9 2-Boom Jumbo*	D	14.00	107.20	80.00	27.20	106.60	80.00	26.60	26.90	Ideal condition
9 2-Boom Jumbo*	D	14.00				106.80	93.70	13.10	13.10	Working condition

(Same ear muff:
* ((1st case) - operator does not move his neck or head, ideal conditions.
((2nd case) - operator under normal working conditions.

the same worker, and on the same machine (Table 6, No. 9). Under ideal conditions, as in the laboratory, the ear muff provided ideal results (26.9 dBA), while under working conditions, attenuation was only about half of that (12.6 dBA).

Assuming that ear muffs are excellent attenuators (which they are not), and that a miner is working in noise levels of 115 dBA (Jumbo-Three Drills), then he would have to wear his muffs 95 percent of the drilling time to lower his exposure to within the 85 or 90 dBA limit. Taking his muffs off for 12 minutes in a four hour drilling period would over-expose the miner to noise. Most hearing loss occurs in the first five years of exposure to noise[26]. A man who has worked in noisy environments for 25 years gains little practical benefit from even the most powerful muffs[27]. Of course, safety organizations in mines must be capable of performing the task of controlling attenuation of ear muffs[28].

CONCLUSIONS

The main problems encountered in ear muffs are caused by the ear cushion seal against the head and their functional design. In comfort tests it was demonstrated that ear muffs with large cushion areas were favoured (Tables 1 and 2). Laboratory tests showed that a difference exists in attenuation between muffs, and a difference also exists in attenuation characteristics between factory (ANSI Z 24.22-1957) and laboratory tests. Methods using short measurements for the determination of a noise exposure index, and modes of control for good muff wearing, were developed in the Elliot Lake Laboratory. Tests in mines showed that only three ear muffs of all those examined have good attenuations:

- No. 5, model E: (23.3 dBA)
- No. 6, model F: (19 dBA)
- No. 10, model J: (22.1 dBA).

All three ear muffs are worn with the compression band passing behind the head. The No. 10 muff has a support strap which improves comfort and maintains a good fit during wear. Causes of poor attenuation are numerous: bad mounting of ear muffs on helmets, improper fitting, interference by hair and eye glasses, improper wearing by miners, unsatisfactory enforcement by supervisory personnel, incomplete training of miners, etc. There was poor agreement in attenuations between laboratory tests and field tests.

Results of this research have indicated that none of the currently manufactured ear muffs tested in this study contain all of the characteristics desirable in an ideal unit.

RECOMMENDATIONS

1. The results suggest that tests, such as those developed in the Elliot Lake Laboratory for ear muff attenuation, should be obligatory.
2. Because of unsatisfactory ear muff attenuation in working conditions, it should be a mandatory requirement that workers wear both ear muffs and ear plugs if the noise level is higher than 105 dBA (various references in the literature recommend 110 dBA).
3. It is recommended that miners use support straps to maintain effective attenuation and positioning of ear muffs which are worn behind the head.
4. Foremen must be capable, through experience and training, of helping and controlling miners to wear their ear muffs properly.
5. The program should be introduced to new miners on hiring.
6. When purchasing ear muffs, practical attenuation results should be taken into account, because the greatest noise reduction is not always given by ear muffs which have the best attenuation characteristics in the laboratory. A new standard is necessary for tests to be uniform under working conditions. This standard would be the impetus to manufacturers to improve their products, and to consumers to develop better judgement in selecting equipment.

ACKNOWLEDGEMENTS

The author wishes to thank all of the mines that have supported the Elliot

Lake Laboratory, and the many colleagues in the mines and the Elliot Lake Laboratory involved.

Thanks are also extended to Dr. P.W. Alberti, Professor of Otolaryngology and Occupational and Environmental Medicine, University of Toronto for granting the opportunity to prepare this paper, and R. Tervo, Manager, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada for helpful suggestions.

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82-128 M.U. Savich

Attenuation of ear muffs in mines

from practice to practice

-iz prakse za prakso

1982

Published in Rudarsko-metalurski,

Zbornik: Mining and Metallurgy Quarterly:

Vol. 29 (4) pp 349-361 1982

ATTÉNUATION DU BRUIT À L'AIDE DE CASQUES ANTIBRUIT DANS LES MINES

M. Savich

Le principal avantage de l'emploi de systèmes de protection de l'ouïe dans les mines canadiennes à des fins de contrôle technique réside dans le fait que nombre de mineurs seront ainsi protégés contre les risques de perte d'audition.

L'étude des casques antibruit comporte trois volets :

1) Méthodes utilisées à l'usine;
2) Essais au Laboratoire d'Elliot Lake;
3) Essais dans les mines souterraines.

Les résultats obtenus dans ces trois séries d'essais ont ensuite été comparés.

RUDARSKO-METALURŠKI ZBORNIK
MINING AND METALLURGY QUARTERLY
LETNIK VOLUME 29 LJUBLJANA 1982 ST. NO. 4

IZ PRAKSE ZA PRAKSO — FROM PRACTICE FOR PRACTICE

Attenuation of Ear Muffs in mines

M. U. SAVICH

1. INTRODUCTION

The major benefit of engineering control through hearing protector usage in Canadian mines is that a number of miners will be protected from a hearing impairment.

The aims of the ear muff studies are outlined under three general headings:

1) Factory procedures;
2) Laboratory tests in the Elliot Lake Laboratory; and
3) Underground mine.

Results obtained under the three general headings were computed and compared.

2. EAR-PROTECTIVE DEVICES

The benefits of reduced noise in mines under two categories:

1) The benefits of reduced risk of hearing loss; and
2) The benefits relating to more plesant working conditions.

There are three basic elements which should be kept in mind in noise and vibration control: a source, a path, and a receiver. The prevention of occupational hazards in the working environment due to noise and vibration should be kept within limits (1) by:

a) technical mesaures;
b) supplementary administrative measures where the technical measures alone do not provide sufficient protection.

Often the noise level cannot be reasonably reduced at its source or by the use of acoustical materials and noise barriers. In such cases, some form of ear protection should be considered for those people who are exposed to the noise.

2.1. The Effectiveness of Ear Protection Devices

The effectiveness of ear-protection devices depends on a number of physical and physiological factors: the nature of the noise, the duration of expo-

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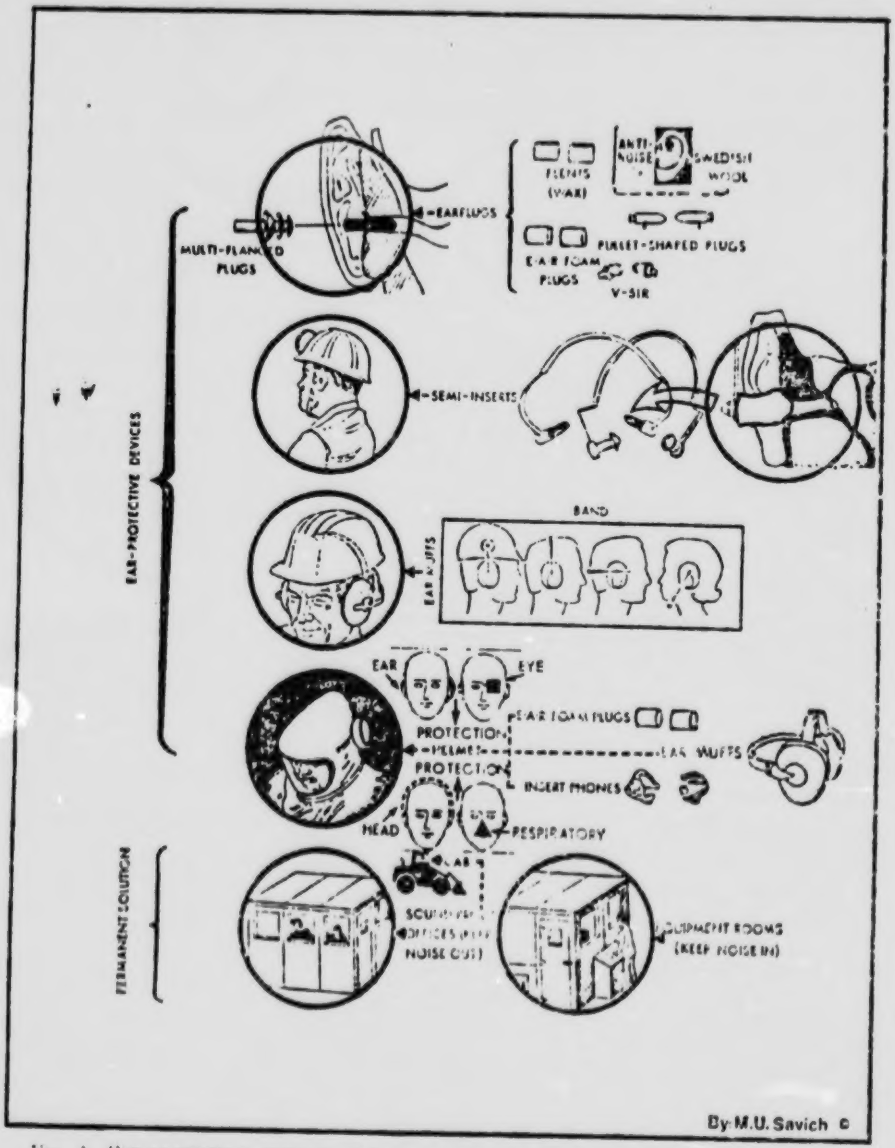

EAR-PROTECTIVE DEVICES
MULTI-FLANGED PLUGS
EARPLUGS
FLENTS (WAX)
ANTI-NOISE
SWEDISH WOOL
PLUGS
PIRLET-SHAPED PLUGS
E-A-R FOAM PLUGS
V-51R
SEMI-INSERTS
BAND
EAR MUFFS
EAR
EYE
PROTECTION
E-A-R FOAM PLUGS
HELMET
EAR MUFFS
PROTECTION
INSERT PHONES
HEAD
RESPIRATORY
PERMANENT SOLUTION
EAR
SOUNDPROOF OFFICES (KEEP NOISE OUT)
EQUIPMENT ROOMS (KEEP NOISE IN)

By M.U. Savich ©

Fig 1. Ear-protective devices and a permanent solution for hearing protection

sure, attenuation characteristics, and possibly other variables. For a person wearing hearing protection, sound energy reaches the inner ear by four different paths:

1) through bone conduction which in effect short circuits the protector;
2) transmitted by vibration of the protective device;
3) by passing through leaks in the protector (which is minimal); and
4) in acoustic leaks around the protective device.

Ear-protective devices can be divided into four categories (Fig. 1) (2).

1) Ear plugs.
2) Semi-inserts.
3) Ear muffs.
4) Helmets.

Ear protectors must comply with the following basic requirements:

1) To achieve high attenuation of ambient noise. The best ear protectors do not attenuate more than 25 to 30 dB. Attenuation is limited to about 50 dB because noise can by-pass the ear-protective device by pick-up and by conduction through the bone of the head (3).

Used by themselves, ear plugs are more effective in attenuation at low frequencies than are ear muffs (Fig. 2). Ear plugs and ear muffs can be worn at the same time to provide greater attenuation. The attenuation offered by the combination is less than the sum of the individual attenuations. This phenomenon has not yet been explained.

2) Be comfortable. An uncomfortable ear protector becomes intolerable after prolonged use.

3) Avoid harmful side effects; such as skin disorders.

2.2. Technical and Attenuation Data of Ear Muffs

Technical and attenuation data on ear muffs is given in Tables 1. Cushion areas, cup volumes and weight vary visibly. Cups are covered by foam on the inside for two reasons: to increase attenuation because uncovered cups permit entry of sound; and to prevent the formation of standing sound waves (the type of waves that are generated in seashells).

2.3. Comfort: One of the Main Requirements of Ear Muffs

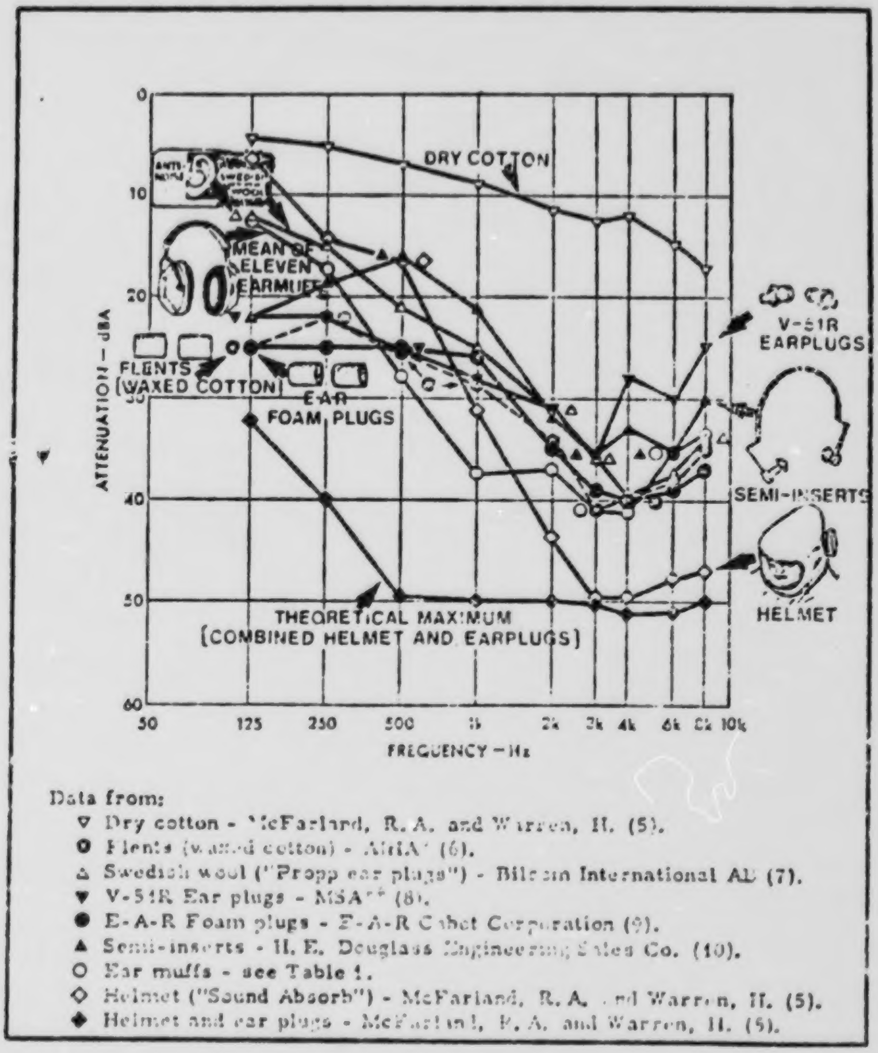
The comfort provided by ear muffs depends upon two factors:

1) the ear cushion seal against the head; and
2) the muff design.

2.3.1. Ear Cushion Seal Against the Head

The pressure of ear cushion seals against the head is a direct consequence of the clamping force, adjustment, softness and weight. **Clamping force (Head force):** The clamping force is the force exerted by an ear muff on the skin and it is the most important element of discomfort. The clamping force against the sides of the head varies between 500 and 1000 g wt.

Adjustment: Ear muff adjustment obviously depends upon the shape and dimensions of a worker's head. A poor linkage between the helmet and the cups hinders clamping force and comfort. Poor mounting of asymmetrical ear muffs is caused by two things; a shortage of manufacturer's data for hole locations' on helmets and the poor mounting of ear muffs on helmets in mines.



Data from:
- ▽ Dry cotton - McFarland, R. A. and Warren, H. (5).
- ◯ Flents (waxed cotton) - AIHA* (6).
- △ Swedish wool ("Propp ear plugs") - Bilsom International AB (7).
- ▼ V-51R Ear plugs - MSA** (8).
- ● E-A-R Foam plugs - E-A-R Cabot Corporation (9).
- ▲ Semi-inserts - H. E. Douglass Engineering Sales Co. (10).
- ○ Ear muffs - see Table 1.
- ◇ Helmet ("Sound Absorb") - McFarland, R. A. and Warren, H. (5).
- ◆ Helmet and ear plugs - McFarland, R. A. and Warren, H. (5).

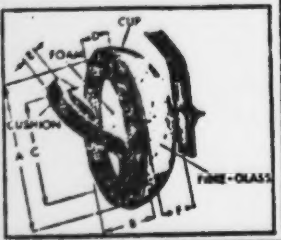
Fig. 2. Attenuation characteristics of ear-protective devices (ANSI Z24.22-57)

* American Industrial Hygiene Association
** Mine Safety Appliances Company

A good solution is to use a support strap in conjunction with a safety helmet. The strap provides support for all ear muff type protectors when worn behind the head (back-band with strap). This head-strap is adjustable over the head to avoid discomfort caused by the pull of gravity on the ear cups. It also helps maintain the ear cups in position.

Softness: Softness is a prime consideration for ear cushions. Apart from the vital aspect of comfort, an effective noise seal depends upon the cushion being soft enough to assume the contours of the head and to fit snugly around the frames of glasses or eyeglass adapters.

Weight: The weight of ear muffs greatly affects comfort because the force of gravity adds to the irritants already present. The total weight of a pair of muffs varies between 151 g and 335 g (Table 1).



No.	Ear Muff	Band	Characteristic	Attenuation in (dB)* 125	250	500	1k	2k	3k	4k	6k	8k
1	A		Measured	9.7	16.1	20.9	33.9	36.9	36.8	41.8	31.8	36.9
			Std. Dev.	3.2	2.5	4.3	[illegible]	2.9	5.4	5.7	6.6	5.9
2	B		Measured	9	19	22	33	[illegible]	41	36	38	35
			Std. Dev.	-	-	-	-	-	-	-	-	-
3	C		Measured	10	19	30	[illegible]	37	45	[illegible]	39	36
			Std. Dev.	-	-	-	-	-	-	-	-	-
4	D		Measured	11.5	[illegible]	[illegible]	26.5	38	38.9	44.5	39.9	-
			Std. Dev.	-		-	-		-	-	-	-
5	E		Measured	13.4	17.3	20.6	29.8	40.7	45.2	[illegible]	32.6	29.3
			Std. Dev.	3.3	3.9	3.0	3.0	3.5	4.6	[illegible]	4.1	4.9
6	F		Measured	17	18	29	36	38	44	44	41	41
			Std. Dev.	4.6	2.4	3.7	3.2	4.1	7.4	6.6	4.7	5.1
7	G		Measured	10	21	33	44	46	47	48	42	30
			Std. Dev.	-	-	-	-	-	-	-	-	-
8	H		Measured	10	21	33	40	44	47	45	42	38
			Std. Dev.	-	-	-	-	-	-	-	-	-
9	I		Measured	18	17	23	35	35	[illegible]	37	38	38
			Std. Dev.	2.5	3.8	4.6	5.6	4.3	4.3	6.7	4.1	2.9
10	J		Measured	13	17	28	39	36	44	36	32	33
			Std. Dev.	2.8	2.6	4.9	4.6	4.5	4.6	3.3	3.4	4.9
11	K		Measured	15	17	26	41	36	38	38	33	34
			Std. Dev.	[illegible]	[illegible]	4.8	[illegible]	4.9	4.5	4.8	4.1	4.1
Σ	* Arithmetic Mean of all Ear Muffs			12.16	17.90	27.6	37.22	38.88	41.87	41.27	35.49	33.31
	Std. Dev.			3.04	2.47	3.09	4.33	3.50	3.9	3.00	7.0	7.30

* Attenuation characteristics measured in accordance with American National Standard Specification Z.24.22-1957 (from Factory Data).

No.	Ear Muff	Fitted Cushion	Band	Cross-sectional Dimensions (cm) A	B	C	D	E	F	Area of Cushion (cm²)	Volume of Cup (cm³)	Weight (g) Cup	Cushion	Foam	Fibre-Glass	Σ wt	Total Weight of Ear Muff (g)
1	A	Foam		9.7	9.7	6.5	4.3	1.1	6.2	47.0	180	49.86	13.67	7.64	-	71.16	[illegible]
2	B	Air		9.8	9.8	6.3	4.2	0.8	4.0	60.0	190	73.04	11.48	1.93	-	88.79	206
3	C	Foam		10.7	8.0	4.7	4.0	1.3	3.6	35.6	157	71.03	[illegible]	3.39	2.65	78.17	163
4	D	Foam		10.5	8.0	4.6	4.5	0.9	3.0	38.3	131	48.33	4.49	1.13	-	55.97	152
5	E	Foam		10.6	8.9	4.6	4.2	1.6	3.8	29.3	151	42.80	6.61	1.27	-	49.13	151
6	F	Foam		9.8	8.3	4.9	3.9	1.0	4.5	45.1	[illegible]	69.04	10.47	0.07	-	81.94	201
7	G	Fluid		11.0	8.1	6.3	3.6	3.7	4.4	38.7	167	68.60	34.27	3.93	-	107.83	229
8	H	Foam		11.4	8.3	5.6	3.7	4.8	4.4	43.5	164	57.62	19.87	4.93	-	81.53	276
9	I	Foam		9.4	6.9	6.9	4.6	1.0	0.0	25.7	171	73.46	8.92	3.21	-	86.07	270
10	J	Foam		9.6	6.9	6.1	4.6	0.9	4.4	30.5	171	76.28	9.03	3.36	-	88.65	275
11	K	Foam		11.0	8.2	6.9	4.1	1.0	3.6	43.3	168	52.92	19.92	2.48	-	71.32	219
Σ	Arithmetic Mean of all Ear Muffs			10.34	8.2	6.62	4.13	0.93	4.17	38.16	153.6	59.90	16.90	3.38	2.65	83.12	248
	Std. Dev.			0.60	0.86	0.31	3.12	0.12	0.4	7.90	20.6	12.16	14.63	2.46	-	29.35	60.9

Table 1. Attenuation characteristics and technical data of ear muffs acquired for testing

2.3.2. The Design of Ear Muffs

Designing is an important requirement, especially for things that are worn. Two main factors in the design of ear muffs are: ease of handling, and choice of materials. Ear muffs have different degrees of symmetry. Usually ear muffs are symmetrical, except those that are mounted on a helmet. Asymmetrical ear muffs mounted on helmets are a major source of poor attenuation.

3. LABORATORY TESTS OF EAR MUFFS

Measurements of ear muff attenuations have been made using two methods:

1. Psychophysical method using human heads by static range-of-movement:

a) Movement of the joint of the neck in normal position. Subject used glasses and adapters.

b) Movement of the joint of the neck, flexion, (dorsal and ventral) and neck rotation (right and left). Subject used glasses.

2. Physical method using apparatus for determining the efficiency of cup cushions.

3.1. Subject Selection and Test Room

Two subjects for these tests were selected from the laboratory personnel. Subject 1 (age 35) with long hair, had a mezzocephalic head with a bizygomatic diameter of 13.6 (significantly smaller than average), and subject 2 (age 54) short haired, had a brachycephalic head with a bizygomatic diameter of 16.5 cm (significantly larger than average).

3.2. Test Procedure Using Human Heads

Fitting Procedure: Each of the subjects was taught the correct fitting procedure for the eleven models. The device was first positioned by the experimenter and then adjusted by the subject for a final orientation for each test.

Attenuation Measurements: Measurements of variation in sound pressure levels for a constant test signal level were made on both the left and right sides of the head. The ear muff attenuation was determined at the following frequencies: 125, 250, 1000, 2000, 4000 and 8000 Hz and at the dBA weighting network using the factory attenuations given in Table 1.

3.3. Effect of Glasses and Adapters on Attenuation of Ear Muffs

Measurements of ear muff attenuations were made in the current series of test with: (a) ear muffs, (b) ear muffs and glasses, and (c) ear muffs, glasses and adapter. Muff/eyeglass adapters were specially designed for people wearing glasses in conjunction with hearing protectors.

The attenuation was observed in a semi-reverberant field with sound direct at the face. The resulting differences in attenuation values over eleven ear muffs are found between subjects and between measurements on the same subject.

On the same subject, left hemisphere versus right hemisphere attenuation differed. Data reduction results were tabulated in the dBA weighting network so that a better understanding and clearer presentation were possible. From the summary results the following can be concluded:

1. Attenuation for subject 2 with large head and short hair was higher than attenuation for subject 1 with small head and long hair, except in four measurements.

2. Ear muffs No. 2, No. 5, and No. 8 had almost equal attenuations for both subjects.

3. The largest attenuation difference for both subjects occurred with the No. 6 ear muff, apparently due to subject 1's long hair. Substantial differences were also found with ear muffs No. 2, 7, 9 and 10.

4. With the use of glasses and their adapters, attenuation decreased. The adapters are not effective sound barriers.

5. Most ear muffs show a lower attenuation given by the factory specification:

Ear Muff No.	1	2	3	4	5	6	7	8	9	10	11
Noise Reduction (dBA)	34.2	31.1	36.3	37.5	39.9	38	43.6	43.6	35	36.3	36.4
Attenuation (dBA)	27.27	29.66	30	29.95	31.54	27.04	29.88	34.77	31.64	32.06	27.23
Difference (dBA)	6.93	1.44	6.8	7.55	8.36	10.96	13.72	8.83	3.36	4.24	9.21
Order of Performance*	5	1	4	6	7	10	11	8	2	3	9

NOTE: * 1 = best; 11 = worst

Only No. 2 ear muff came close to the factory attenuation value, The largest attenuations was displayed by ear muff No. 8.

3.4. Effect of Movement of Joint of the Neck, Flexion and Neck Rotation, on Attenuation of Ear Muffs

Ear muff attenuation measurements were performed in four positions:

1. Neck flexion:
a) Dorsal — head elevated;
b) Ventral — head lowered.

2. Neck rotation:
a) Right — head turned right;
b) Left — head turned left.

The tests were similar to the previous tests, because these events were often repeated. From the results the following can be concluded:

1. There are no great differences in attenuation when the neck moves.
2. Test performed on subject 1 (D = 13.6 cm) showed that the amount of hair trapped between the ear muff cushion and the head had a significant effect on ear muff attenuation.

3. The largest difference in attenuation between two subjects is once again with the No. 6 ear muff (left side 16 dBA and right side 16.06 dBA)

4. The greatest attenuation occurred with the No. 10 ear muff on both subject (34.21 dBA).

5. On the average, with both subjects, glasses decreased attenuation by 1.42 dBA.

6. Again the attenuations is less than the factory specification.

Ear Muff No.	1	2	3	4	5	6	7	8	9	10	11
Noise Reduction (dBA)	34.2	31.1	36.8	37.5	39.9	38	43.6	43.6	35	36.3	34.4
Attenuation (dBA)	29.98	28.99	29.79	30.72	27.88	26.92	—	31.84	29.25	34.21	29.09
Difference (dBA)	4.22	2.11	7.01	6.78	12.02	11.08	—	11.76	5.75	2.09	5.31
Order of Performance*	3	2	7	6	10	8	—	9	5	1	4

NOTE: * 1 = best; 10 = worst

Ear muffs No. 2 and No. 10 had the best efficiency with reference to the factory attenuation. Also ear muff No. 10 demonstrated the best attenuation of all ear muffs.

3.5. Cushion Seals and Clamping Force

Attenuation mainly depends upon two factors: clamping force and cushion seals. Eye-glass adapters do not have the characteristic attributed to them in the literature (4). The cause is simple: new materials for cushion seals perform the function of adapters.

3.6. Physical Method

Ear muff attenuation was measured as the difference between the outputs of the microphone uncovered and the cup covered microphone. For this test the apparatus to determine the efficiency of cup cushion under different clamping forces (Fig. 3).

The algebraic difference in sound pressure levels, in the dBA weighting network, at each test frequency signal, with and without the ear cup in place on the plexiglass is considered to be the attenuation of the device. The attenuation data and efficiency of cup cushions could be divided into three main groups:

Group	Ear Muff	Minimum Force (g wt)	Attenuation Behaviour
1	No. 4, No 5, No. 8, No. 9 and No. 10	150 to 350	Steady at all frequencies and clamping forces above minimum
2	No. 1, No. 3 and No. 6	350 to 550	Steady at some frequencies and clamping forces
3	No. 2, No. 7 and No. 11	> 550	Variable at all frequencies and clamping forces

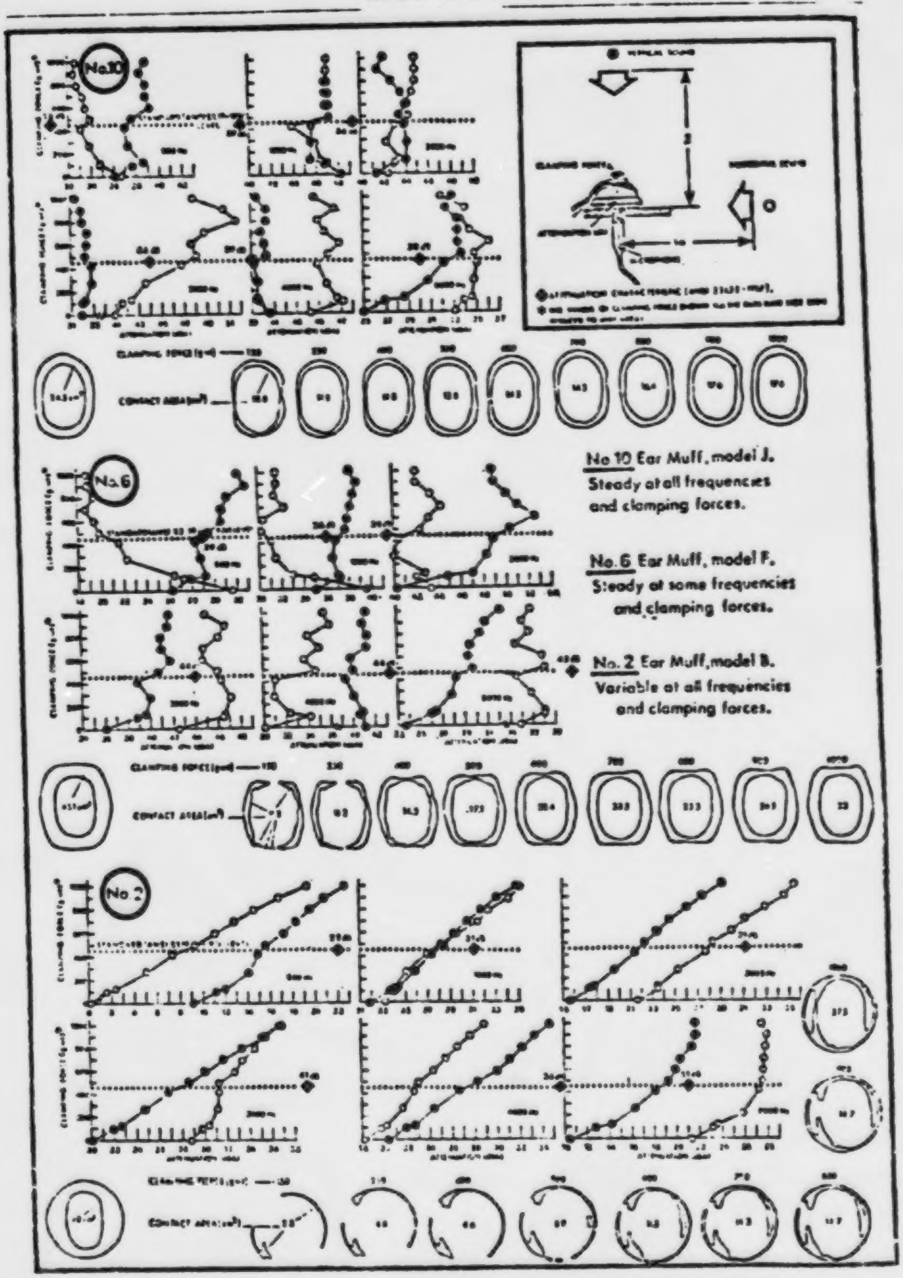


Fig. 3. Typical attenuation data and contact plots of cup cushions

In general, the attenuation values of ear cups are dependent upon two factors:

1. Clamping (head band) force (g wt), and
2. Design of the ear cup cushion.

Both factors were taken into consideration in this test. It is evident that attenuation is a function of size of air paths as shown by poor contact in Fig. 3.

This test explained the following:

1. Ear muffs with a small cushion area start serving their purpose more quickly because the force per square centimeter is larger;
2. A clamping force larger than 900 g wt, in the first and second groups, does not cause an increase in attenuation;
3. Attenuation characteristics (ANSI Z 24. 22-1957) of ear muffs show a correlation with physical test. They cannot be completely compared because their values differ, dB versus dBA.

Based on the extensive literature and the physical tests performed, the apparatus for determining the efficiency of cup cushion can be used effectively to apply theory in the design of ear muffs.

4. EAR MUFF ATTENUATION TESTS IN MINES

A study was undertaken to measure ear muff attenuation in mines. A series of nine ear muffs was tested under uniform conditions in mines. The Noise Dosimeter Vest provides a technical solution for the determination of the noise exposure index and the attenuation of ear muffs. These tests require only two dosimeters and a stop watch. The dosimeters have small microphones and provide accurate short time readings of the noise exposure index. Also a pocket-sized calculator designed for sound amplitude analysis should be utilized (dBA, L_{eq}, L_{max} and time duration of the sampling period. The surveyor must measure the distance between the bony structures just forward of the ears (bizygomatic diameter) using an outside caliper. On the basis of bizygomatic diameter measurements, the clamping force can be evaluted.

4.1. PARTICIPANTS

In this study one man at each of three working sites was chosen:

1. Jumbo (Three Drills) operator
2. Drill Hydrofore operator
3. Jaw Crusher operator

It was explained that all testing would be conducted under the full support of miners and supervisory personnel.

4.2. RESULTS

The results of the study indicate poor attenuation of ear muffs in underground mining conditions. As a results of analyzing the data obtained, three major findings are presented below.

Jumbo (Three Drills) Operator: On the basis of obtained results, it is evident that the noise levels are high (115 dBA) and that the ear muffs supplied do not offer adequate protection. For all ear muffs, one of the factors contributing to the low attenuation found was this man's extremely small head size. The ear muffs with adequate attenuation were Nos. 1, 2, 5 and 10. The jumbo operator judged ear muffs which are worn behind the head (Nos. 6 and 11) to be poor providers of comfort. Also, such ear muffs have poor attenuation.

Hydrofore Drill Operator: A hydrofore drill (hydraulic-electric fan) has no air exhaust noise and thus produces low noise levels at low frequencies. Because the attenuation of ear muffs is better at high frequencies, it should be expected that their efficiencies would be wery high. The results demonstrate that good attenuations were obtained by ear muffs Nos. 5, 6 and 10, with band passing behind the head. The other ear muffs did not provide satisfactory attenuations.

Jaw Crusher Operator: Test results from eight ear muffs show sufficient attenuation, 90 dBA and below. Only ear muff No. 9 had a very low attenuation (8.3 dBA). Once again, extremely good attenuation was provided by three muffs, No. 5 (18.8 dBA), No. 6 (23.8 dBA) and No. 10 (23.1 dBA).

4.3. Clamping Force

Clamping force studies were made with eleven ear muffs. The mean value is 1256 ± 77 (g wt) (Standard error is ± 77 (g wt)). In various references in the literature it can be found that a clamping force can vary between 500 and 1600 grams (5). The data in the literature differ from practical data. Manufactures have increased clamping forces in their products thus creating discomfort for the wearer. They did this because they are well aware that too small a pressure results in the creation of air leaks.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The most important function of an ear muff is that it will attenuate noise while providing a comfortable fit. Manufacturers claim that ear muffs are shaped to fit all ears comfortably; this is not always the case. Some of the main problems encountered in ear muffs are caused by the ear cushion seal against the head and their functional design. In comfort tests it was demonstrated that ear muffs with large cushion areas were favoured.

The noise levels reaching the ears were calculated by a computer model for ear muffs fitted by either the octave-band or the sound level conversion method. The method provides an acceptable basis for selecting ear muffs in any industrial noise spectrum not dominated by intense pure tone or narrow-band energy components.

Tests in mines showed that only three ear muffs of all those examined have good attenuation:

— No. 5, model E: (23.3 dBA)
— No. 6, model F: (19 dBA), and
— No. 10, model J: (22.1 dBA).

All three ear muffs are worn with the compression band passing behind the head. The No. 10 muffs has a support strap which improves comfort and maintains a good fit during wear. Causes of poor attenuation are numerous: bad mounting of ear muffs on helmets, improper fitting, interference by hair and eyeglasses, improper wearing by miners, unsatisfactory enforcement by supervisory personnel, incomplete training of miners, etc.

Laboratory tests showed that a difference exists in attenuation between muffs, and a difference also exists in attenuation characteristics between factory (ANSI Z 24.22-1957) and laboratory tests. There was poor agreement in attenuations between laboratory tests and field tests.

Results of this research have indicated that none of the currently manufactured ear muffs tested in this study contain all of the characteristics desirable in an ideal unit.

5.2. Recommendations

1. The results suggest that obligatory tests, which were developed in the Elliot Lake Laboratory for ear muff attenuation, should be introduced.

2. Because of unsatisfactory ear muff attenuation in working conditions, it should be a mandatory requirement that workers wear both ear muffs and ear plugs if the noise level is higher than 105 dBA (various references in the literature recommend 110 dBA).

3. It is recommended that miners use support straps to mantain effective attenuation and positioning of ear muffs which are worn behind the head.

4. Foremen must be capable, through experience and training, to help and control miners in their task of properly wearing ear muffs.

5. Introduce the program to new miners at the start of employment.

6. When purchasing ear muffs, practical attenuation results should be taken into account, because the greatest noise reduction is not always given by ear muffs which have the best attenuation characteristics in the laboratory. A new standard is necessary for tests to be uniform under working conditions. This standard would be the impetus to manufactures to improve their products, and to consumers to develop better judgement in selecting equipment.

O uporabi slušnih varoval v rudnikih

(Povzetek)

M. SAVICH

V kanadskih rudnikih uporablja kakih 50 % delavcev naušnike, 40 % ušesne čepe in kaki 3 odstotki ušesne čepe in naušnike. Ostalih 7 odstotkov ne uporablja sredstev za varovanje sluha ali pa jih uporablja samo včasih. Zato smo opravili posebno raziskavo, da bi ugotovili učinkovitost naušnikov. V rudnikih navadno uporabljajo dve vrsti ušesnih čepov: iz rumene in bele penaste gume. Druge vrste ušesnih čepov le redko uporabljajo ali pa sploh ne. Glavni vzrok za to so dobro zmanjševanje hrupa, lagodnost, primerna raba in tudi nizka cena.

Glavne značilnosti enajstih naušnikov, ki jih je mogoče kupiti smo raziskovali v laboratoriju in jih analizirali psihofizično in fizično.

Raziskave so pokazale naslednje učinke:

— oblika čelade ima pomemben vpliv na zmanjšanje hrupa zaradi različnega pritiska;

— preizkušnje so pokazale, da zrak med naušnikom in glavo samo zmanjša učinek naušnikov;

— zmanjšanje hrupa in lagodnost nošnje med seboj nista povezana;

— pri uporabi naočnikov in njihovih prilagajeval se hrup manj zmanjša. Prilagajevala niso učinkovita za dušenje hrupa;

— pri sukanju vrata ni velikih razlik v zmanjšanju hrupa;

— učinkovitost različnih vrst naušnikov ni enaka;

— naušniki z majhno površino blazinice so boljši zaradi večje sile na enoto površine;

— pritisk višji od 900 g pri večini naušnikov ne povzroči zmanjšanja hrupa;

— značilnosti zmanjšanja hrupa z naušniki (ANSI Z24.22-1957) se nekako skladajo s fizikalnimi raziskavami.

Od enajstih naušnikov smo jih devet preiskovali pod enotnimi pogoji v rudnikih. Od vseh teh so se odlikovali trije. Vsi trije imajo jermen na vratu. Naušnik s podložnim paščkom, ki napravi naušnik bolj lagoden in se pri nošenju dobro prilagaja, je pokazal najvišje zmanjšanje hrupa. Vzrokov za majhno zmanjšanje hrupa je precej: slaba pritrditev naušnikov na čelado, neprimerno prilagajanje, motnja zaradi las in naočnikov, nepravilna nošnja, majhna skrb nadzornikov, nezadostna vajenost rudarjev itd.

Sklepi teh raziskav so pokazali, da prav noben naušnik, ki smo jih v tem programu preiskovali, nima vseh lastnosti, ki bi jih želeli imeti, v idealni obliki.

Zaradi nezadostnega znižanja hrupa z naušniki pri delovnih pogojih (15 dBA ali manj) naj bi bila zahteva, da delavci nosijo tako naušnike kot čepe, če je stopnja hrupa višja od 105 dBA (nekateri viri priporočajo 110 dBA), obvezna.

Pot k uresničevanju naj bi bila naslednja:

— nadzornik mora znati pomagati in nadzorovati rudarje, da bi naušnike pravilno nosili;

— o načinu nošenja moramo rudarje obvestiti;

— vzdrževati moramo stalen kontakt s proizvajalci naušnikov.

Vprašanje je, ali moremo uporabljati sedanji standard. Avtor misli, da bi morali najti nov standard, ki bo upošteval tudi delovne pogoje.

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Clamping force durability test

1984

ESSAIS DE CONSTANCE DE LA FORCE DE SERRAGE

par

K.C. Butler* et M.U. Savich**

RÉSUMÉ

La constance de la force de serrage des nouveaux casques antibruit "no noise" couramment utilisés dans les mines de l'Ontario a été étudiée. On utilise une méthode peu coûteuse consistant à tordre le casque d'avant en arrière à l'aide d'un façonneur et d'un petit compteur. Aucune défaillance n'a été observée avec les trois casques antibruit essayés. Les nouveaux casques conviennent mieux car la force de serrage demeure constante après un usage prolongé (au moins deux à trois ans). Grâce à sa simplicité, cet essai peut être facilement utilisé dans l'industrie minière.

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CLAMPING FORCE DURABILITY TEST

by

K.C. Butler* and M.U. Savich**

ABSTRACT

An investigation was conducted on the clamping force durability of the new generation "No-Noise" ear muffs which are commonly used in Ontario mines. An inexpensive method, using a shaper with a small counter was used to flex the ear muffs in a back and forth direction. Results indicated no failure in any of the three ear muffs tested. The new generation ear muffs are more suitable since the clamping force remains constant after long use, (a minimum two to three year period). The simplicity of this test makes it easy to repeat in the mining industry.

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INTRODUCTION

In Ontario mines, the "No-Noise" ear muff manufactured by Hellberg Protection AB of Gothenburg, Sweden, is commonly used (Fig. 1). This type of ear muff was investigated by several authors, and unsatisfactory attenuation was found to occur (1-4). Even though these ear muffs had poor attenuation, they were very popular in mines, mainly for two reasons: light weight and low price. The poor attenuation of this type of ear muff was in connection with weak clamping force. Old generation ear muffs used a metal arm for clamping force, which in many cases became bent and lost tension resulting in reduced efficiency. Hellberg Protection Company recognized this problem and introduced a new type of ear muff to the market (Fig. 2). The two main differences between the old generation and new generation ear muff are the larger volume cup and significant improvements in clamping force.

The block connector of a new generation ear muff was taken apart for

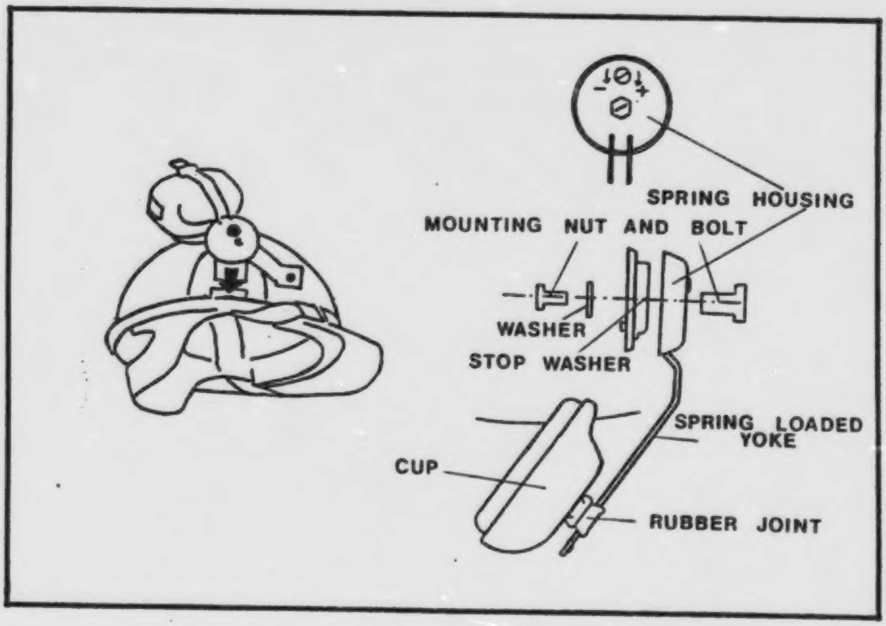

Fig. 1 - Old generation "No-Noise" ear muff,
Hellberg Protection AB, Gothenburg.

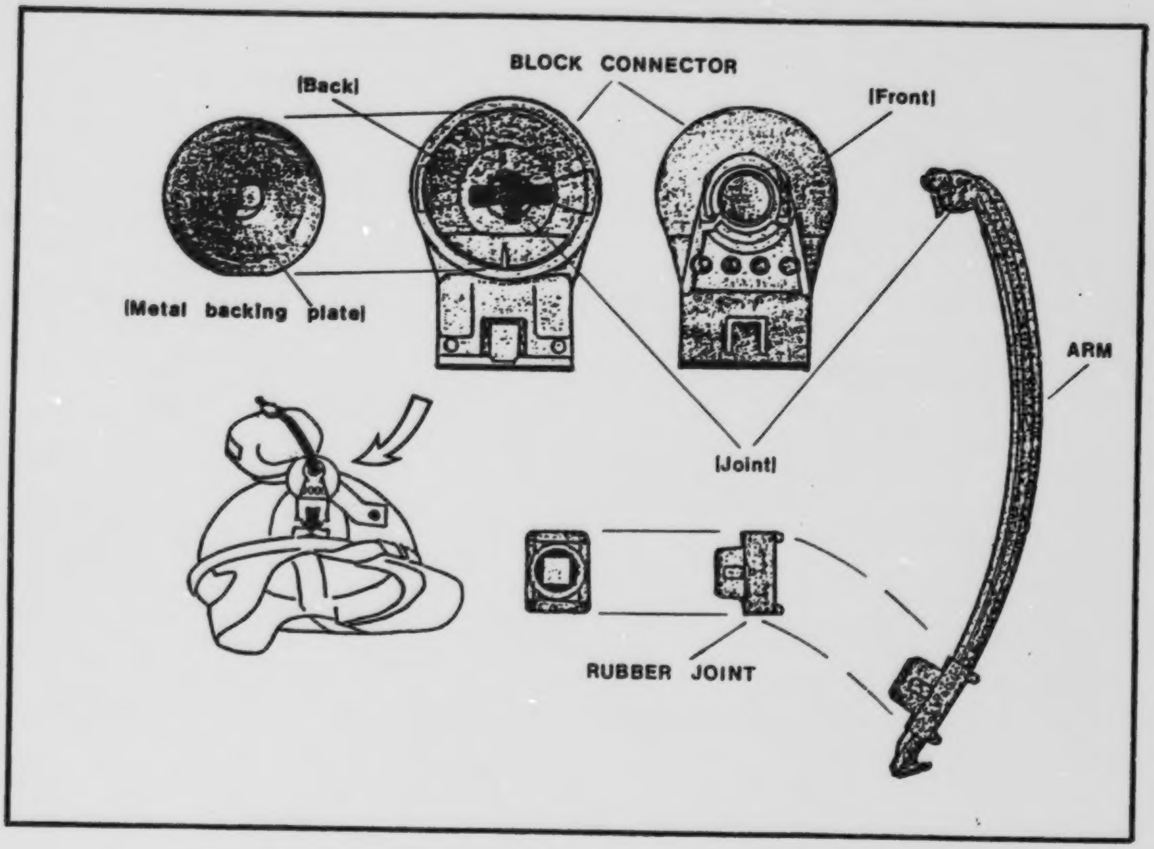
BLOCK CONNECTOR
[Back]
[Front]
[Metal backing plate]
ARM
[Joint]
RUBBER JOINT

Fig. 2 - New generation "No-Noise" ear muff,
Hellberg Protection AB, Gothenburg.

inspection. This part of the muff is very simple with only two moving parts; the arm and a tensioned metal backing plate.

The ear muff arm is manufactured of very hard durable solid plastic with no reinforcing material inside. This provides rigidity with little fatigue after prolonged flexing. Also, wear at the joint is further minimized by using a light grease for lubrication.

The purpose of this study was to test the clamping force durability of this new generation of ear muff.

TEST

The power source used to flex the ear muffs was a 26 inch Standard

Crank Shaper manufactured by Canada Machinery Corporation of Cambridge, Ontario (Fig. 3). The stroke length of the muff was adjusted to 8.25 cm (3¼ in). This stroke length approximates the distance an ear muff is moved from its position on the wearers' ears to its resting place on the hard hat and vice versa. The number of strokes of the muff was recorded using a small, inexpensive hand held counter (≃ $10.00), attached to a magnetic base indicator holder. The counter was positioned directly in front of the shaper lathe head and upon each forward stroke of the ram, as the ear muff was flexed, a pencil (rubber pin) fastened to the head of the ram would gently strike the push button of the counter. For each recorded count the ear muff moved through one inner and one outer stroke. The safety hat was fastened to a sheet of plywood (30 cm x 35 cm), which in turn was attached to the side of the shaper lathe table. The ram head tool holder had a "paddle" shaped board attached to it which was positioned against the inner cushion of the ear muff and attached to the base of this board was a steel band with a 1 cm wide strip cut in the middle. This band was wrapped around the outer surface of the ear muff. Its purpose was to secure and pull the muff on each forward stroke of the ram.

RESULTS

A total of six muffs were to be tested (Table 1). The stroke speed of the shaper lathe was adjusted to approximately 17 counts per minute, and at each 50 count interval the shaper lathe was stopped and the block connector and arm were inspected for any failure. After 300 counts, the inspection interval was increased to 100 counts. Upon reaching 3,800 counts a time interval was now adopted, using ten minute periods in which the shaper lathe was stopped and the muff was inspected. At the 10,000 count point, the stroke

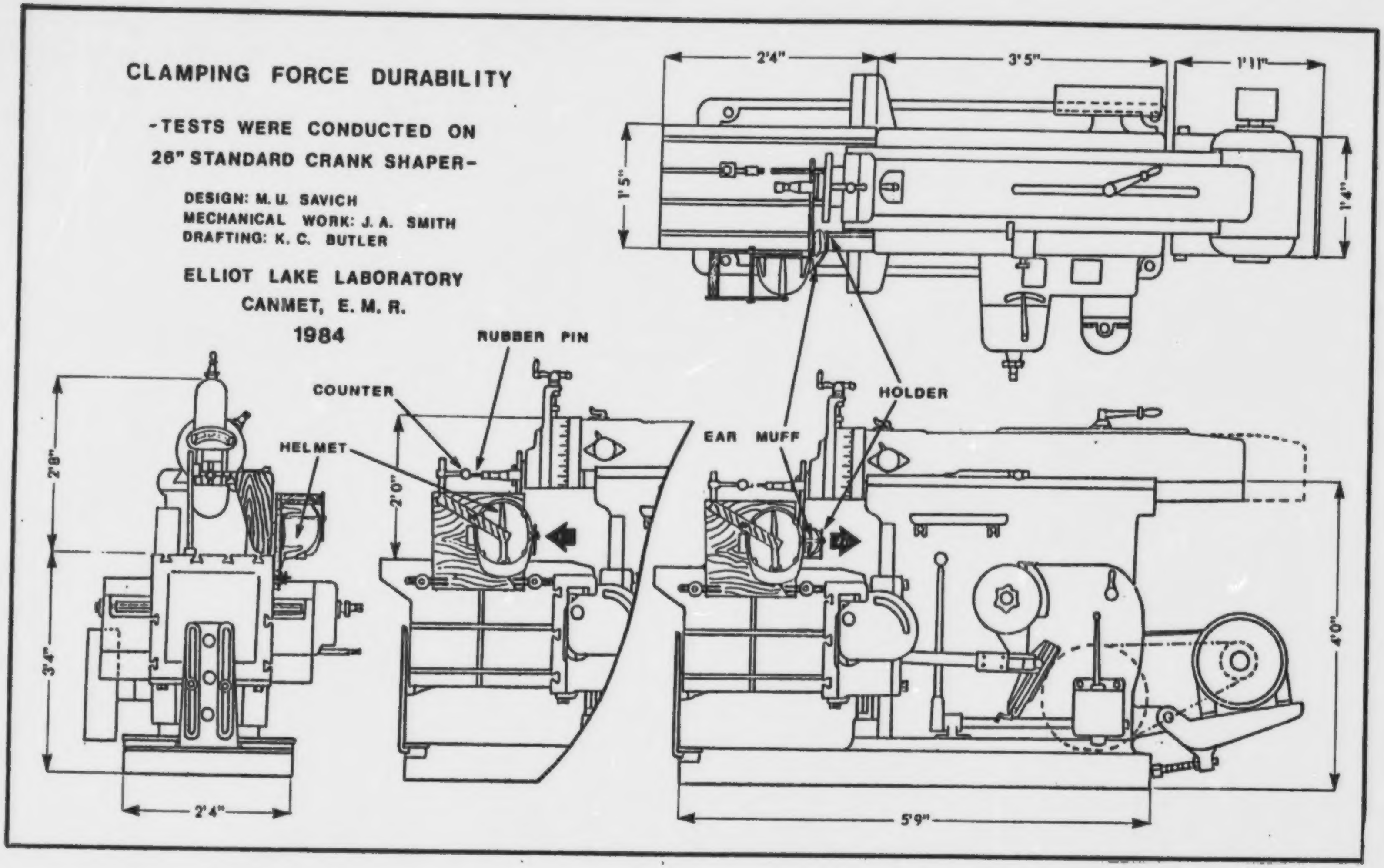
CLAMPING FORCE DURABILITY
-TESTS WERE CONDUCTED ON
26" STANDARD CRANK SHAPER-
DESIGN: M. U. SAVICH
MECHANICAL WORK: J. A. SMITH
DRAFTING: K. C. BUTLER
ELLIOT LAKE LABORATORY
CANMET, E. M. R.
1984
2'4"
3'5"
1'11"
1'5"
1'4"
RUBBER PIN
COUNTER
HELMET
HOLDER
EAR MUFF
2'8"
3'4"
2'0"
4'0"
2'4"
5'9"

Fig. 3 - Clamping force durability tests were conducted on 26 in Standard Crank Shaper manufactured by Canada Machinery Corporation, Cambridge, Ontario.

Table 1 - Clamping force durability test.

"No-Noise" Ear Muff	Number of Counts
1	15,000
2	Not tested
3	15,000
4	Not tested
5	15,000
6	Not tested

speed was increased to approximately 25 counts per minute with an inspection every ten minutes. After 15,000 counts, testing on ear muff No. 1 was stopped. Testing was started on ear muff No. 3 at a stroke speed of 25 counts per minute and an inspection every ten minutes. After 9,500 counts the stroke speed was increased to approximately 53 counts per minute. After 15,000 counts testing was stopped without any failure. Ear muff No. 5 was now substituted and tested at a stroke speed of 53 counts per minute up to 15,000 counts. Since none of the ear muffs had failed and there was no observable wear, it was decided that further testing of the remaining three (3) ear muffs was not warranted.

CONCLUSION

The clamping force durability of the new generation of "No-Noise" ear muffs has been tested and found to be very good. The old generation "No-Noise" ear muff had poor attentuation due to the small cup size and the design of the arm causing it to be easily bent by the wearer resulting in poor clamping force. The three new generation "No-Noise" ear muffs were all flexed to a 15,000 count without either the block connector or arm failing. Assuming a worker removes the ear muffs between 20 to 30 times per shift, the muffs should last a minimum of two to three years. Since the clamping force pressure is not adjustable in the new generation "No-Noise" ear muff, this results in a more constant clamping force.

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VOL. 2 Report 11

86-58 M.U. Savich and J.K. Weglo

Attenuation measurement of ear muffs at Falconbridge complex : No. 5 shaft, the East mine and the mill and smelter, 1984

1986

ATTENUATION MEASUREMENT OF EAR MUFFS AT FALCONBRIDGE COMPLEX: NO. 5 SHAFT, THE EAST MINE, AND THE MILL AND SMELTER, 1984

by

M.U. Savich* and J.K. Weglo**

ABSTRACT

Ear muffs are the main protection of the mining workforce for the attenuation of noise.

The measurment of head size as against clamping force as well as the condition of the ear muffs are demonstrated as important variables in this attenuation of noise.

The "NO NOISE" ear muffs attenuation was about 10 dBA average with a standard deviation of 4.1 to 5.6 dBA at the Falconbridge Complex.

The Mark V ear muffs replacing those in this study, based on clamping force measurements versus head size can be expected to produce attenuation of less than 14 dBA.

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MESURE DE L'EFFICACITÉ DES CASQUES ANTIBRUIT À ATTÉNUER LE BRUIT AU COMPLEXE FALCONBRIDGE: AU PUITS N° 5, À LA MINE EST, AU MOULIN ET À LA FONDRIE, 1984

par

M.U. Savich* et J.K. Weglo**

RÉSUMÉ

Les casques antibruit sont la principale source de protection contre le bruit pour les travailleurs miniers.

La mesure de la taille de la tête par rapport à la force de serrage ainsi que l'état des casques antibruit sont indiqués comme étant d'importantes variables de l'atténuation du bruit.

Lors de l'étude au Complexe Falconbridge, le niveau d'atténuation du bruit "NO NOISE" des casques antibruit était en moyenne d'environ 10 dBA avec un écart type de 4,1 à 5,6 dBA.

Cependant, d'après les mesures de la force de serrage par rapport à celles de la taille de la tête, les casques antibruit Mark V qui ont remplacé les casques utilisés dans cette étude pourraient assurer une atténuation du bruit de moins de 14 dBA.

---

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INTRODUCTION

As part of the program of reducing noise, measurements were taken at all Falconbridge Mines and the ear muffs used there were tested for efficiency.

At Falconbridge Mine the following ear muffs were tested:

1) "NO NOISE", model NN3-F, the Hellberg Standard Volume Hearing Protector, hard hat attachment;
2) Mark IV, MSA, worn behind the head;
3) Mark V, Ear Cup Kit, MSA, hard hat attachment;
4) Peltor H7P3e, hard hat attachment; and
5) Bilsom Viking Muff 2314, hard hat attachment.

Testing was mostly done on "NO NOISE" ear muffs, model NN3-F, because 95% of the workforce used this model. Means and methods of testing, and theoretical and practical considerations of data, are described in the main report, and should be read to compare the Falconbridge Complex with other mines.

The latter three muffs have only recently begun to be used at the mine. On the Mark V Ear Cup Kit only head size and clamping force were tested.

Attenuation characteristics of the ear muffs as supplied by the manufacturer using the ANSI protocol (reference) are given in Table 1. From Noise Reduction Rating (NRR) data also supplied by the manufacturer, it can be concluded that all ear muffs provide relatively equal attenuation.

MEASUREMENTS AND RESULTS

It was not possible to complete a substantial number of tests because of a small number of work places. Instruments were greatly affected by the moisture in the mines, which accounted for most of the malfunctions we had. One microphone was outside the ear muff, and one was between the cup and the subjects ear. Brüel and Kjaer (B and K) dosimeters do not indicate readings greater than

Table 1 - Attenuation characteristics of ear muffs acquired for testing ANSI S.319-1874.

No.	Ear Muff	Charac-teristic	Frequency Hz 125	250	500	1000	2000	3150	4000	6300	8000	NRR
1	"NO NOISE" Model NN3-F, Hellberg	Mean	16.2	19.9	25.2	34.1	36.0	39.2	39.0	40.3	38.1	24
		Std. Dev.	2.5	1.8	2.0	1.7	2.2	3.1	2.0	4.0	4.1	
2	Mark IV, MSA	Mean	17.0	18.0	29.0	36.0	38.0	44.0	44.0	43.0	43.0	24
		Std. Dev.	2.6	2.6	3.1	3.2	4.1	7.2	4.6	4.7	5.7	
3	Mark V Ear Cup Kit MSA	Mean	14.9	20.2	28.2	35.0	33.4	35.4	33.5	33.1	32.2	24
		Std. Dev.	2.6	1.5	1.9	2.5	2.1	2.8	2.6	2.7	3.0	
4	Peltor H7P3e	Mean	14.1	18.8	28.1	36.2	35.6	38.4	35.0	35.5	36.4	24
		Std. Dev.	2.1	2.0	3.0	2.1	2.2	2.3	2.1	2.1	2.4	
5	Viking Muff No. 2314 Bilsom	Mean	15.0	21.0	27.0	37.0	36.0	38.0	42.0	42.0	39.0	25
		Std. Dev.	1.8	2.0	2.5	2.8	1.5	2.3	3.0	3.7	3.6	

115 dBA or less than 89 dBA. For this reason, it was often impossible to obtain the exact ear muff attenuation. Both instruments were either OSHA (doubling at 5 dB), or ISO (doubling at 3 dB), monitoring noise levels simultaneously. Sound level tests with the hand-held instruments took longer to complete. Head size was measured with outside calipers, and clamping force with a manual balance.

HEAD SIZE AND CLAMPING FORCE

Head size and clamping force tests were carried out on five different ear muffs using different populations. The results can be found in Appendices A and B, and the summary results in Table 2.

From Table 2 it is clear that clamping force was weakest on the first two ear muff types, which had been in use for a long time. The Institute of Occupational Medicine (IOM) in the United Kingdom is carrying out extensive research on hearing protectors for the National Coal Board, and the European Community has found that a typical muff, after three months use in a mine, provides only a quarter of the protection of a brand new muff (1). This was largely because of a reduction in the force exerted by the head band. From Table 2, the last two types of ear muffs were used by too small a population to allow evaluation.

Constructed normal frequency curves of a population of 34 (clamping force tests) have a mesokurtic shape; and those of a population of 46 (attenuation tests) have a bell-shaped curve (Figure 1). There are heads with a markedly small bizygomatic diameter, between 11.5 and 12.5 cm. The frequency curve for clamping force data has positive skewness (skewed to the right), with the large tail of distribution to the right (Figure 2). The low maximum occurs because of the markedly smaller heads surveyed here. From the diagram of population versus clamping force (Figure 2), it is clear that ear muff deterioration occurs along the entire interval from 400 (gwt) to 1500 (gwt). This is why we should not expect good attenuation of ear muffs. Bar graphs were constructed from the data

Table 2 - Summary results of head size and clamping force tests

No	Ear Muff	N*	Head Size (cm)		Clamp Force (gwt)		
			Mean	Std. Dev.	Mean	Std. Dev.	
1	"NO NOISE" Model NN3-F, Hellberg	39	14.14	0.54	990.44	322.22	Used long time
2	Mark IV, MSA	10	13.65	0.50	980.00	303.65	Used long time
3	Mark V, Ear Cup Kit, MSA	6	10.04	0.19	1170.83	128.86	Almost new
4	Peltor H7P3e	2	14.00	-	1300.00	-	Almost new
5	Viking Muff No. 2314, Bilsom	1	14.00	-	1350.00	-	Almost new
Σ(2-5)		19	14.01	0.53	1025.00	301.00	

Note: * Population

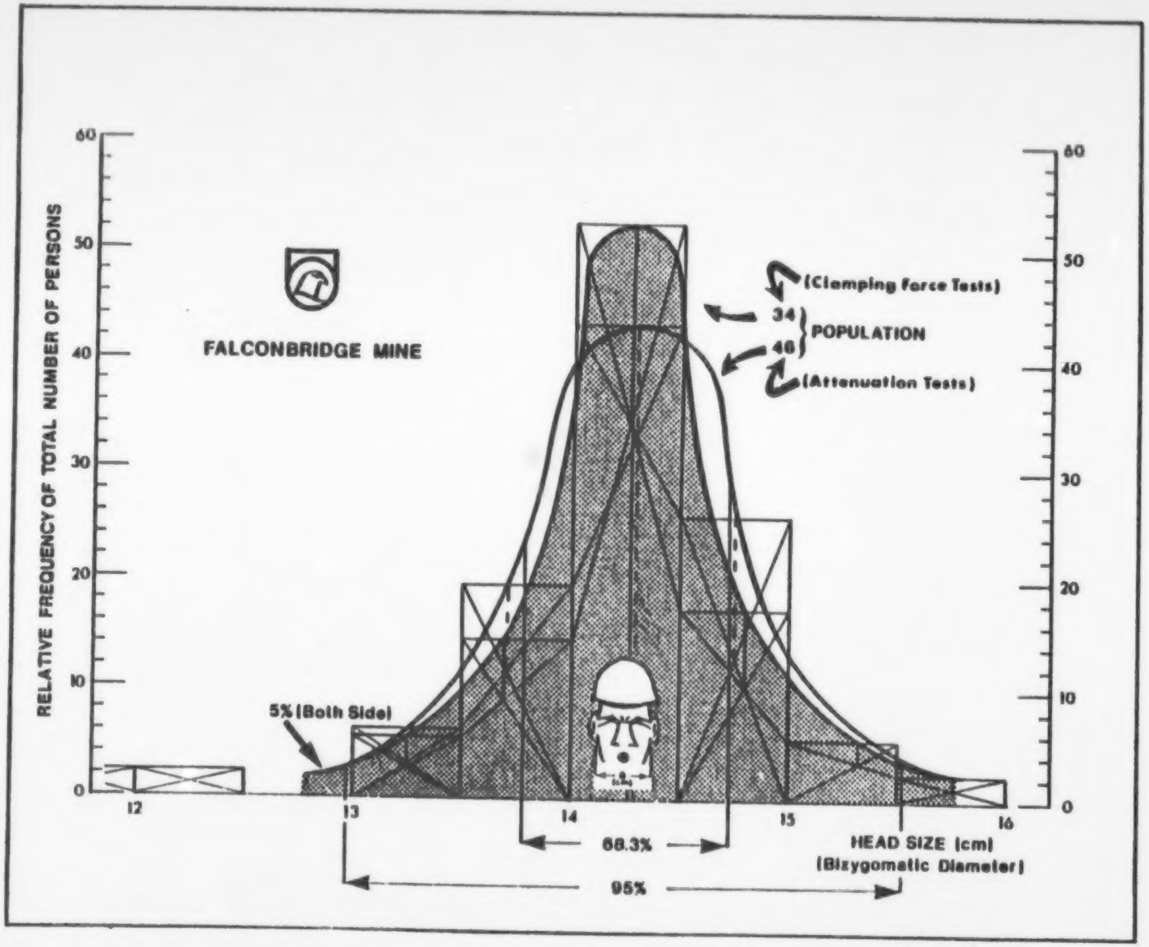

Fig. 1 - The normal curve is known as mesokurtic while the more peaked curve is called leptokurtic (population of 34), and the symmetrical frequency curve or bell-shaped curve (population of 46) of head size tests.

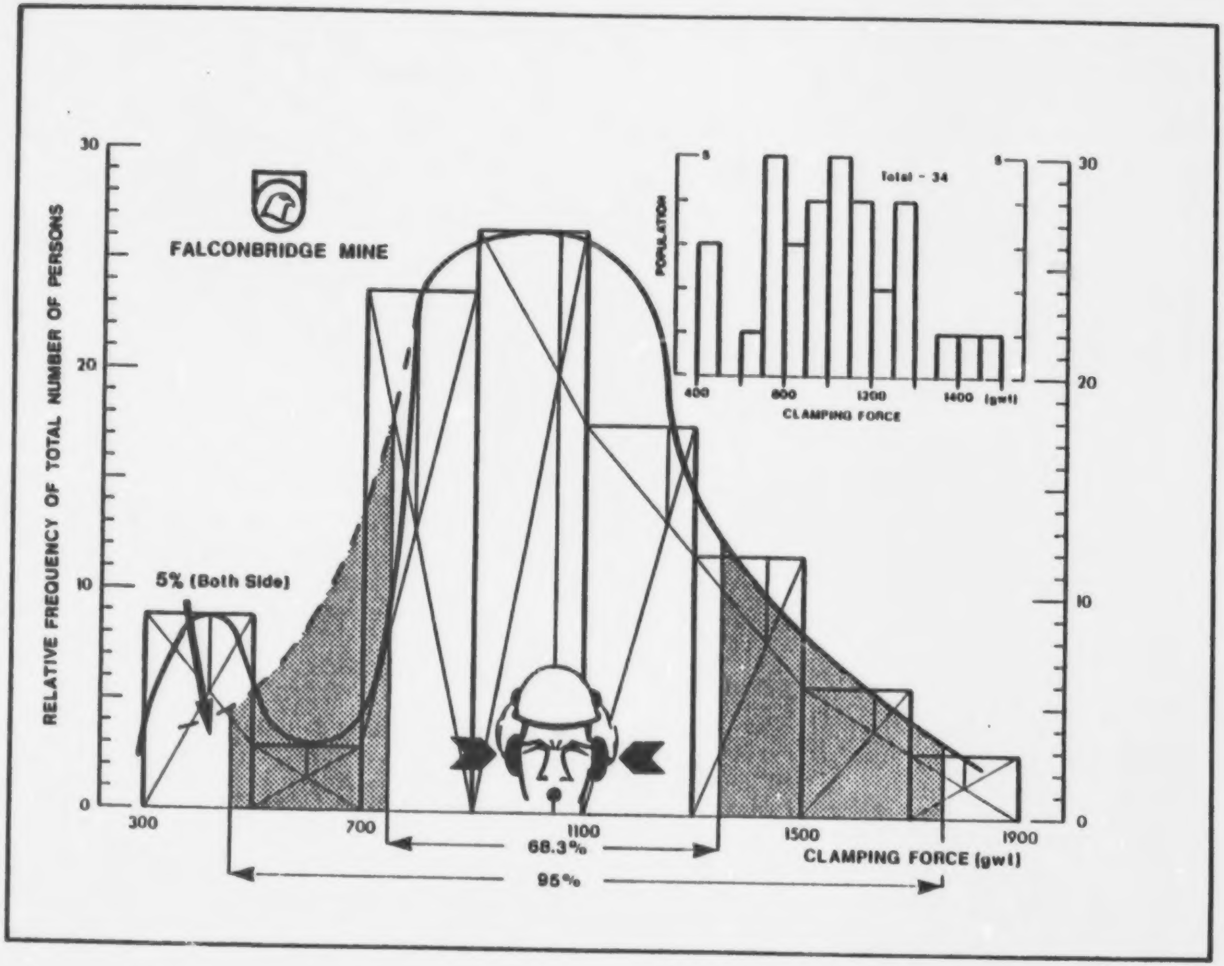

Fig. 2 - The clamping force frequency curve has positive skewness, but it also has two maxima.

on "NO NOISE" muffs for a population of 34 (Figure 3). It is obvious that clamping force is not in direct relationship with head size, due to ear muff deterioration. Data from Appendix A was used to construct a standard deviation (error) ellipse (Figure 4). In this construction it is evident that the ellipse does not cover the plotted field of clamping force versus head size, and therefore the attenuation would be expected to be low. The error ellipse yields a qualitative result from quantitive content.

In the mine at the 500 level with a Joy A.L. 60 jackleg six frequency analyses were performed, their averages being:

Frequency (Hz) in dB									dBA	dBC
31.5	63	125	50	500	1k	2k	4k	8k		
93.0	106.3	106.0	110.0	109.0	111.2	107.0	108.4	107.0	116.0	117.4

The following equation can be used to estimate the sound level (dBA) at a worker's ear when wearing a personal hearing protector:

$$dBA = dBC - (NRR - 10)$$

where dBC is the C-weighted sound level to which the worker is exposed, NRR is the Noise Reduction Rating of the protector, and 10 is a factor used to "derate" the NRR to conditions consistent with the "real world". Based on this equation the sound level at a jackleg driller's ear (in dBA), when working at a location where the sound level is 117.4 dBC and using a personal hearing protector rated at NRR = 24 would be 103.4 dBA. For a noise attenuation of 12.6 dBA. Further protection from noise pollution will be achieved by using ear plugs in conjunction with muffs. By measuring ear muff attenuation we can check the accuracy of the formula.

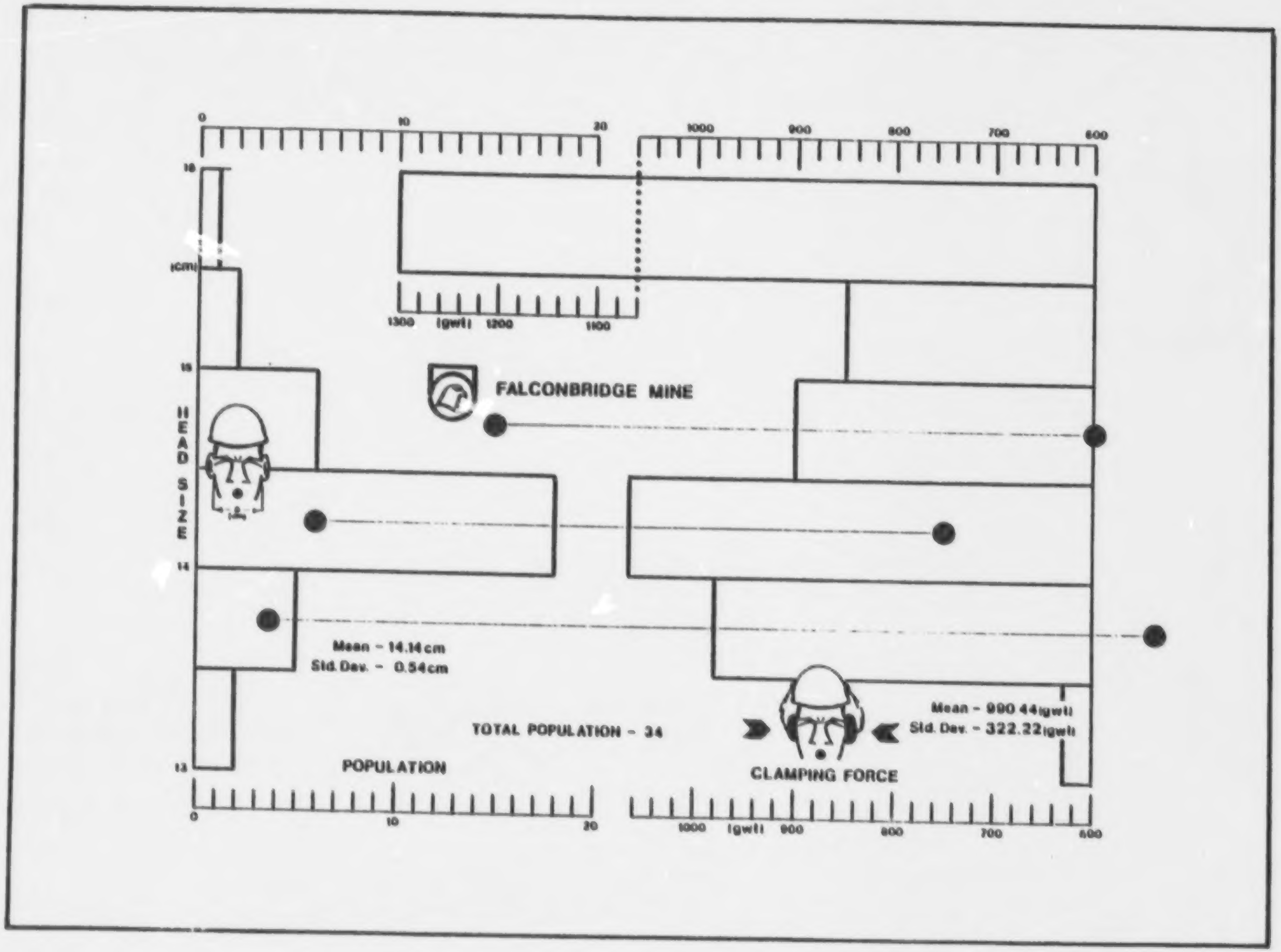

Fig. 3 - Relationships between head size and clamping force at the Falconbridge Mine.

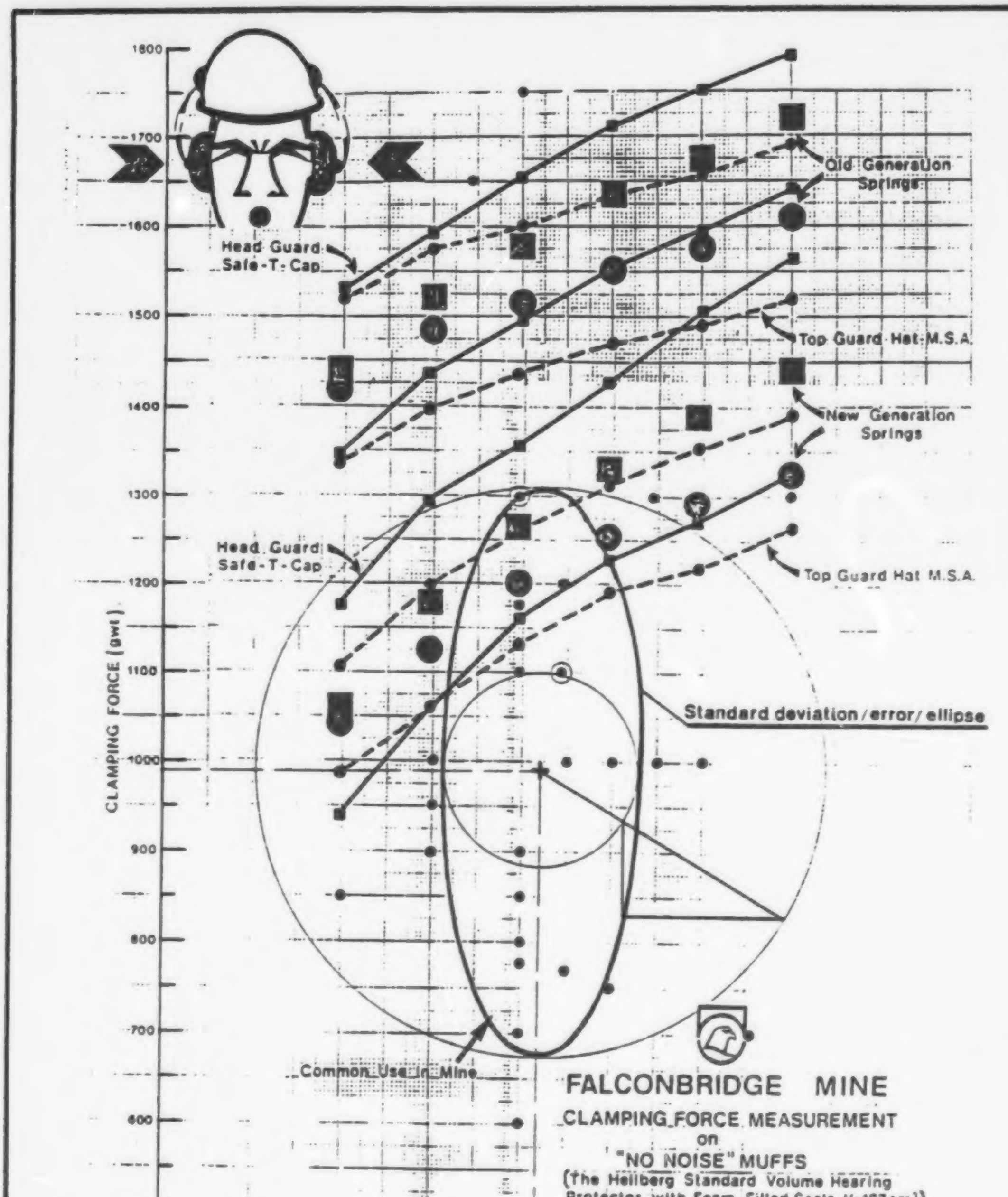

Fig. 4 - Standard deviation (error) ellipse of "NO NOISE" muffs at Falconbridge Mine.

CONDITION OF EAR MUFFS

The ear muffs were not in good condition (Table 3).

Table 3 - Tests of ear muff conditions in mines and mills

No.	Ear Muff	N*	Condition of Ear Muff					
			Good		Fair		Poor	
			N_1	Percent	N_2	Percent	N_3	Percent
1	"NO NOISE" (NN3-F)	34	23	67.65	8	23.53	3	8.82
2	Mark IV, MSA	10	2	20.00	7	70.00	1	10.00
3	Mark V Ear Cup Kit, MSA	6	6	100.00	0	0.00	0	0.00
4	Peltor H7P3e	2	2	100.00	0	0.00	0	0.00
5	Viking Muff No.2314, Bilsom	1	0	0.00	0	100.00	0	0.00
1-5	Σ	53	33	62.26	16	30.19	4	7.55

Note: *Population ($N^* = N_1 + N_2 + N_3$)

Workers had a tendency to bend the springs on "NO NOISE" ear muffs to make them more comfortable. This action caused the deterioration of ear muffs attenuation. The clamping force test will quantify the amount of deteriioration.

It should be noted that the Mark IV MSA ear muffs were in very poor shape and had been used for a long time. Shortly after these tests they were replaced. Other ear muff models were of more recent "vintage". This experience shows that, if anything, more care should be taken in the maintenance of ear muffs.

ATTENUATION MEASUREMENTS

Attentuation measurements were performed on the following ear muffs:

1) "NO NOISE" model NN3-F, 23 measurements (Appendix C);

2) Mark IV, MSA, 9 measurements (Appendix D);

3) Peltor H7P3e, 9 measurements (Appendix E);

4) Bilsom Viking Muff 2314, 5 measurements (Appendix F);

Testing was carried out on various types of equipment: Joy jacklegs and stopers, Gardner Denver jumbo drills, in-the-hole (ITH) drills, mucking machines, scooptrams, crushers, ball mills and smelter.

Tests of "NO NOISE" ear muffs show the following attenuations (Appendix C):

Characteristic	dBA	90% Conf. Limit	95% Conf. Limit
OSHA mode - Mean	9.42	9.42 ± 3.06 dBA	9.42 ± 3.84 dBA
Std. Dev.	5.57		
ISO Mode - Mean	10.19	10.19 ± 2.14 dBA	10.19 ± 2.59 dBA
Std. Dev.	4.11		

Considering the position of the error ellipse, Figure 4, this poor attenuation could have been expected. This is proof that the error ellipse provides good results from short and quick measurements (Appendix A). The painstaking procedure of measuring attenuation with dosimeters is not necessary if clamping force versus head size are evaluated. Controlling clamping force; controlling the wear and tear on ear muffs; and maintaining or replacing outright those muffs that have begun to show signs of deterioration (visible or invisible) are necessary for good attenuation control.

MARK IV MUFFS

An even poorer attenuation, and a large standard deviation (due to the small population), was achieved by the Mark IV, MSA ear muffs:

Characteristic	dBA	90% Conf. Limit	95% Conf. Limit
OSHA mode - Mean	8.39	9.42 ± 3.06 dBA	9.42 ± 3.84 dBA
Std. Dev.	6.99		
ISO mode - Mean	8.20	10.19 ± 2.14 dBA	10.19 ± 2.59 dBA
Std. Dev.	6.39		

Confidence in results is low because only nine measurements were taken. With the other two types of ear muffs, Peltor H7P3e and Bilsom Viking 2314, measurements were not evaluated.

EAR MUFF COMFORT

Overall, ear muff comfort was deemed good by the workers (Table 4). "NO NOISE" ear muffs had poor attenuation, but they were judged positively for comfort.

Table 4 - Comfort of ear muffs in mines and mills

No.	Ear Muff	N*	○ -Satisfactory		◒ -Good		● -Very good	
			N	Percent	N	Percent	N	Percent
1	"NO NOISE" (NN3-F)	23	7	30.4	15	65.2	1	4.3
2	Mark IV, MSA	9	2	22.2	7	77.8	0	0.0
3	Peltor H7P3e	9	2	22.2	7	77.8	0	0.0
4	Viking muff No.2314, Bilsom	5	0	0.0	4	80.0	1	20.0
1-4		46	11	23.9	33	71.7	2	4.5

Note: * Population (N* = N + N + N)

Seventy per cent of the employees thought comfort was good or better, while 30% were only satisfied. If we consider this result against the area covered by the error ellipse in Figure 4, we can see that only 20% of the ellipse area covers the field of ear muff clamping force. Comfort and clamping force have diametrically opposing results of almost equal magnitude:

"NO NOISE" Ear Muffs		○-Satisfactory	◒-Good
	Comfort	30.4%	68.5%
	Area of error ellipse	Non-coverage 80.0%	Coverage 20.0%

It becomes clear why attenuation is poor (≈10 dBA), and that the problem lies in clamping force efficiency.

From field work observations, surveyors found that safety glasses are uncomfortable and sometimes painful when worn with ear muffs.

CONCLUSIONS

Measurements performed at Falconbridge Mine have shown that the efficiency of "NO NOISE" ear muffs is poor, and that their attenuation at this mine is no more than 10 dBA. Many variables affect the "real world" attenuation of ear muffs at this mine:

- type of muffs (helmet or head band);
- condition of muffs (hard or flat cushion, torn seal, bent arms, etc.);
- fitting of muffs (seated correctly, or incorrectly);
- physical considerations (shape and size of head, size of ears);
- job functions (required amount of head turning); and
- physical obstructions (eye glasses - some thicker wands, larger gap, cause discomfort also).

The jackleg drill still gives off more than 105 dBA after attenuation by ear muffs. Ear plugs are not capable of reducing noise by a further 15 dBA to reduce the noise to the 90 dBA level. Ear muff control should be continued by measuring head size and clamping force with the apparatus suggested in the main report.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the help and cooperation of E. Isaacs, Director, and P. Savalas, Field Technical staffe of M.A.P.A.O., as well as L.H. Rajala and N.A. Girard, Senior Mine Supervisors, Dr. A.G. Cecutti, Medical Director, D. McPhee and R. Desjardins, Technicians, and J. Dwyer, Safety Dept. of Falconbridge Ltd.

Acknowledgement is also extended to J. Vergunst, Working Environment Engineer, Ontario Ministry of Labour, Sudbury, and R. Pleasance, Manager, Levitt-Safety Ltd., (Metrosonics Inc.), Sudbury for the loan of the instruments.

Thanks are extended to G. Knight, Research Scientist, Elliot Lake Laboratory for reviewing this manuscript and making numerous helpful suggestions.

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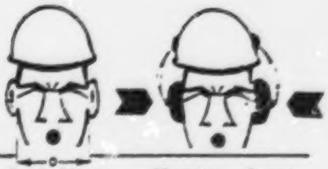
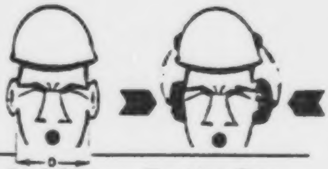
Head size and clamping force data of "NO NOISE", model NN3-F ear muffs



No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Driller	2	14.75	1200
2	Driller	1	14.00	900
3	Driller	3	14.00	850
4	Driller	3	14.50	1000
5	Driller	1	15.00	1000
6	Driller	1	13.00	850
7	Driller	1	14.75	400
8	Raise Driller	2	13.50	1000
9	Raise Driller	1	13.00	400
10	Trammer	2	14.25	1200
11	Trammer	1	14.00	1750
12	Trammer	1	14.00	1500
13	Trackman	2	13.75	1650
14	Trackman	1	14.00	1175
15	Conveyor Operator	1	14.00	1200
16	Motorman	1	14.75	1000
17	Deckman	1	14.50	950
18	Mechanic - Heavy Equipt.	1	14.00	1300
19	Crusherman	1	15.50	1300
20	Stope Boss	2	13.75	400
21	Stope Boss	3	14.00	600
22	Stope Boss	1	13.50	900
23	Stope Boss	2	14.50	750
24	Stope Boss	2	13.50	950
25	Stope Boss	1	14.25	775
26	Stope Boss	1	14.00	700
27	Shift Boss	1	14.25	1200
28	Shift Boss	1	14.25	1000
29	Geology	1	14.00	1100
30	Engineering	1	14.00	1300
31	Ventilation Man	2	14.00	775
32	Ventilation Man	1	15.25	700
33	Ventilation Man	1	14.00	800
34	Ventilation Man	1	14.25	1100
	Mean:		14.14	990.44
	Std. Dev.:		0.54	322.22

Note: 1 - Good; 2 - Fair; 3 - Poor.

Head size and clamping force data of different muffs: MSA Mark IV; MSA Mark V Ear Cup Kit; Peltor H7P3e; and Bilsom Viking muff 2314



MARK IV MUFFS

No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Driller	2	12.50	500
2	Driller	2	14.00	1400
3	Driller	2	13.50	600
4	Driller	3	13.50	700
5	Stope Boss	2	13.50	900
6	Stope Boss	2	14.25	1050
7	Level Cleaner	1	13.75	975
8	Ventilation Man	1	13.50	1175
9	Noise Analyst	2	13.75	1200
10	Noise Analyst	2	14.25	1300
	Mean:		13.65	980
	Std. Dev.:		0.50	303.65

MARK V MUFFS

No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Stope Boss	1	14.00	950
2	Trammer	1	14.00	1200
3	Crusherman	1	14.25	1100
4	Carpenter Foreman	1	14.25	1300
5	Noise Analyst	1	13.75	1200
6	Noise Analyst	1	14.00	1275
	Mean:		14.04	1170.33
	Std. Dev.:		0.19	129.36

PELTOR MUFFS (H7)

No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Noise Analyst	1	14.00	1300
2	Noise Analyst	1	13.75	1175

BILSOM MUFF (2314)

No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Driller	2	13.50	1350
Σ	Mean:		14.01	1025.00
	Std. Dev.:		0.53	301.00

Note: 1 - Good; 2 - Fair; 3 - Poor.

Attenuation tests of "NO NOISE" model NN3-F, the Hellberg Standard Volume Hearing Protector, in OSHA and ISO modes

No.	Equipment	Comfort		L_{OSHA} (dBA)	OSHA Attenuation (dBA)			L_{eq} (60s) (dBA)	ISO Attenuation (dBA)			dBA			Comments	Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.	Slow	Fast	Peak		
1	Jack Leg Drill (D. Tymchuck)	◒	14.5	98.7	20	17.3	18.7	111.2	-	-	-	-	-	-	Drilling completed too fast. SIM readings appear low.	No. 5 shaft, 4500 level, 7447 stope.
2	Jack Leg Drill (M. Rheault)	◒	14.5	114.6	14.1	14.5	14.4	117.4	17.7	15.63	16.66	117	117.5	132.2	Two drills operating in close quarters.	No. 9 shaft, 4500 level, 4447 undercut.
3	Jack Leg Drill (R. Durette)	◒	13.0	115	5.9	9.6	7.8	115.4	14.4	0.45	7.43	116.8	117.5	131.5		No. 5 shaft, 500 level, 4650 undercut.
4	Jack Leg Drill (A. Legault)	◒	13.75	115	15.5	6.6	11.1	116.1	4.8	8.8	6.8	115.8	116.0	131.7		No. 5 shaft, 500 level, 4650 undercut.
5	Jack Leg Drill (G. Robichaud)	◒	13.0	114.2	16.3	18.6	17.5	116.8	22.9	8.9	15.9	117.7	117.1	131.5		No. 5 shaft, 1900 level, 5268 No. 2 hole undercut.
6	Stoper Drill - Rock Bolting (S. Smith)	○	14.0	105.5	4.3	0.8	2.6	100.0	-	-	-	85.3	93.7	109.7	Ear muff arms intentionally bent; "too much vibration". Wears plugs and muff; ISO - malfunction.	5300 level, East Mine.
7	Jumbo Drill (two boom) (C. Plante)	◒	14.25	109.5	10.3	10.1	10.2	110.0	18.3	2.3	10.3	110.7	110.6	121.6		No. 9 shaft, 4300 level, 4152 stope.
8	"Long Tom Drill" (two Booms) (S. Smith)	○	14.0	115.0	-	-	-	118.3	-	-	-	114.3	118.8	130.8	All readings inside and outside muffs were 115 dBA. Dosimeter failed on left side test.	5300 level, East Mine.
9	In the Hole Drill - I.H (A. Demers)	○	14.0	100.9	21.2	20.5	20.9	100.5	11.19	19.6	15.19	99.7	99.9	115.3	Normally wears plugs only.	5100 level, East Mine.
10	In the Hole Drill - I.R.M. (V. Faucher)	◒	13.5	92.6	11.0	12.1	12.6	94.5	11.2	12.59	11.89	93	93.3	111.1		5500 level, East Mine.
11	Mucking Machine (G. Gainer)	◒	13.5	107.3	8.9	17.3	13.1	106.5	1.9	10.6	7.25	106.5	109.4	124.4		No. 5 shaft, 300 level, 6698 backs.
12	Slusher (F. Tessier)	◒	12.0	95	0.3	8.3	4.3	96	8.23	3.6	5.92	95.6	96.5	109.7	Poor seal on left ear, very difficult to fit muff.	No. 9 shaft, 4800 level, 5002-4547 undercut.
13	Slusher (R. Weaver)	◒	13.5	99	18.7	12.1	15.4	97.3	13.24	17.0	15.12	96.4	96.9	110.3		No. 5 shaft, 1900 level, 5268, No. 1 hole undercut

No.	Equipment	Comfort		L_{OSHA} (dBA)	OSHA Attenuation (dBA)			L_{eq} (60s) (dBA)	ISO Attenuation (dBA)			dBA			Comments	Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.	Slow	Fast	Peak		
14	Scooptram - Wagner	○	11.5	105.5	3.1	0.2	1.7	100.4	-	-	-	103	103.5	120.7	RACAL Airstream Helmet may limit clamping force, especially on this small head. ISO malfunction.	3500 level, East Mine, No. 25 draw point.
15	Scooptram - Jarco (S. Millar)	○	14	94.7	4.3	>17.1	>10.7	92.8	3.83	9.37	6.6	94.2	93.5	108.3		No. 9 shaft, 4300 level, 5152 stope.
16	Primary Crusher, 4100 Level (P. Lalonde)	○	14.5	96.9	>16.2	>17.6	>16.9	95.2	>27.3	>26.9	>27.1	94.7	94.9	114.2	Mr. Lalonde finds ear plugs better than "muffs".	No. 5 shaft, 4100 level, crusher.
17	Primary Crusher, 6100 Level (P. Lalonde)	○	14.5	106.9	4.0	10.8	7.4	104.5	10.5	1.0	5.75	104.8	104.8	117.8	Very heavy vibration area due to vibrating pass feeding.	No. 5 shaft, 6100 level, crusher.
18	Tertiary Crushers - Operating Floor (R. Cruikshank)	●	14	95.9	1.8	13.3	7.6	94.9	3.64	>14.5	>9.07	95.4	95.6	107.9	Worker borrowed muff, normally wears plugs only.	Fine crushing plant.
19	Tertiary Crushers - Operating Floor (P. Savalas)	◓	14.5	100.6	>19.7	>21.5	>15.6	96.6	11.1	14.6	12.63	95.2	95.3	108.8		Fine crushing plant.
20	Ball Mill Operator Area (P. Savalas)	◓	14.5	88.7	>10	>8.3	>9.2	92.5	11.3	>13.26	>12.28	92.0	91.7	107		Falconbridge Mill.
21	No. 1 Electrostatic Precipator (P. Savalas)	◓	14.5	88.5	>8.1	>8.9	>8.5	94.6	11.93	>12.18	>12.15	89.9	91.4	106.5		Smelter.
22	Converter Punchers (P. Savalas)	◓	14.5	96.2	16.0	15.4	>15.7	99.1	>19.76	15.19	>17.47	100.3	100.4	115.8	Majority of time behind punchers - not normally for this occupation.	Smelter.
23	No. 7 Converter Skimmer - Fluxing (P. Savalas)	◓	14.5	85.8	-	>4.9	-	86.6	>1.66	>2.4	>1.03	84.5	86.0	102.4		Smelter.
	Mean		13.71	99.02	8.0	10.6	9.42	102.49	11.14	9.23	10.19	101.06	102.10	116.87		
	Std. Dev.		0.84	7.67	6.47	6.18	5.57	9.51	5.53	5.80	4.11	10.50	10.18	9.80		

Note: ○ Satisfactory; ◓ Good; ● Very good.   Undetermined numbers (> No.) are not in Mean value.

Attenuation tests of Mark IV, MSA ear muffs, in OSHA and ISO modes

No.	Equipment	Comfort		L_{OSHA} (dBA)	OSHA Attenuation (dBA)			L_{eq} (60s) (dBA)	ISO Attenuation (dBA)			dBA			Comments	Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.	Slow	Fast	Peak		
1	Jack Leg Drill (A. Schuck)	-	13.5	>115	-	-	-	106.5	-	-	-	119.7	118.3	131.3	Ear muff cushions very hard. Cups full of water, Mal-function.	2900 Level - East Mine 3102-3133 undercut.
2	Jack Leg Drill (G. Kaiser)	◒	13.5	>110.1	>30	>25.4	>27.7	116.1	-	>19	-	115.9	115.6	132.2	Mark V. Dosimeters were taken out of operation.	No. 5 shaft, 3500 level.
3	Jack Leg Drill (A. Poropat)	●	14	114.3	2.6	5.8	4	116.7	1.2	7.6	4.4	118.5	117.3	131.8	Drilling in progress nearby.	No. 9 shaft, 4800 level 5002-4547 undercut.
4	Jumbo Drill (Two Boom) (A. McGuire)	●	13.5	106.8	5.4	11.3	8.4	111.1	8.47	5.87	7.17	111.2	113.3	125.6	"Too noisy, especially when glasses worn".	No. 5 shaft, 2900 level
5	Mucking Machine (H. Charette)	◒	14.25	107	0.6	2.7	1.65	105	2.59	2.54	2.56	102.5	102.3	116.8	Plugs and muffs worn. "Muffs alone too noisy".	5300 Level, East Mine.
6	Mucking Machine (L. Lachance)	◒	13.5	105.6	12.2	13.1	12.7	106.5	14.8	>12.7	>13.75	110	109.7	125.2		No. 5 shaft, 300 level 6698 Sacks
7	Mucking Machine (A. Poropat)	●	14	103.1	5.0	1.6	3.3	104.6	10.0	2.5	6.25	104.8	104.9	120.7		No. 9 shaft, 4900 level undercut.
8	Slusher - Joe (L. Lachance)	◒	13.5	-	-	7.5	-	91.2	6.7	9.8	8.25	91.8	92.3	107.6	Dosimeters failed - No test on left side.	No. 5 shaft, 300 level
9	Slusher (H.G. Kolianck)	○	14.75	105.5	13.0	27.1	20.1	100.5	20.57	21.14	20.57	103.8	104.3	117.8	Large head. Apparent attenuation.	No. 5 shaft, 300 level 4650 undercut and fill.
	Mean		13.83	107.05	6.47	9.87	8.39	107.58	9.11	8.24	8.20	108.69	108.67	123.11		
	Std. Dev.		0.45	1.81	5.06	8.67	6.99	8.54	6.62	6.93	6.19	8.94	8.51	8.27		

Note: ○ Satisfactory, ◒ Good, ● Very good

Undetermined numbers (> No.) are not in Mean value.

Attenuation tests of Peltor (H7P3e) ear muffs, in OSHA and ISO modes

No.	Equipment	Comfort		L_{OSHA} (dBA)	OSHA Attenuation (dBA)			L_{eq} (60s) (dBA)	ISO Attenuation (dBA)			dBA			Comments	Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.	Slow	Fast	Peak		
1	Compressor Room (D. Jobin)	◒	14	R.S. (89.1)	-	-9.3	-	91.9	-11.4	4.9	8.15	90.3	89.7	103	Head band, prefers these muffs to plugs or no noise muffs.	No. 5 shaft, compressor boiler house.
2	Secondary Crusher - Belt Picker (H. Felske)	○	14.75	92.6	10.1	-12.2	-11.2	92.9	2.56	5.34	3.95	93	93.3	108	Head band. This man had no hearing protection at all.	No. 5 shaft, Rock house.
3	Secondary Crusher - Belt Picker (H. Felske)	○	14.75	93.6	6.7	0.3	3.5	90.9	0.13	4.9	2.47	90.6	90.9	104.8	Head band. Very large ears. Poor fit on right side as ear was showing.	No. 5, Rock house.
4	Secondary Crusher - Belt Picker (R. Hull)	◒	13	87.2	3.1	-5.8	-4.5	90.1	-10.6	10.7	-10.64	90.1	91.1	106	Head band. This man had no hearing protection at all.	No. 5, Rock house.
5	Ball Mill Operator (D. Jobin)	◒	14	88.9	-8.5	-9.3	-8.9	92.3	12.26	-12.2	12.2	92.9	92.4	106.8	Ball mill operator wears plugs only.	Mill
6	Power House (I. Tiessen)	◒	14	98.7	17.2	-20.2	-18.7	94.0	-14.1	-15.2	-14.65	96.9	96.5	107.5	Outside control room "Very pleased with these muffs".	No. 2, Power house.
7	Converter Skimmer - Fluxing (R. Hull)	◒	14.28	82.5	-	-4.9	-	97.4	21.6	-19.3	-20.45	96.9	94.9	109.3	"Will not work without his muffs".	Smelter. No. 7 Converter
8	Converter Puncher (D. McPhee)	◒	14	97.9	-17.5	-18.2	-17.9	98.3	-16.5	-16.2	-16.3	98.8	98.6	112.1		Smelter No. 7 Converter
9	Electrostatic Precipitator (D. McPhee)	◒	14	91.4	-9.3	-13.5	-11.4	98.0	11.8	-14.0	-12.9	95.3	93.9	111.9		Smelter No. 1 Electrost. Prec.
	Mean		14.00	91.98	-	-	-	93.5	9.67	6.95	-	93.42	93.26	107.7		
	Std. Dev.		0.52	3.15	-	-	-	3.6	8.58	3.25	-	2.87	2.66	3.08		

Note: ○ Satisfactory, ◒ Good, ● Very good

Undetermined numbers (> No.) are not in Mean value.

Attenuation tests of the Bilsom Viking muff 2314

No.	Equipment	Comfort		LOSHA (dBA)	OSHA Attenuation (dBA)			Leq (60s) (dBA)	ISO Attenuation (dBA)			dBA			Comments	Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.	Slow	Fast	Peak		
1	Scooptram JS221 (C. Boulard)	●	14	96.2	30.1	>16.2	>23.2	100.5	8.3	15.4	6.85	103.8	104.3	117.8	Comfort (2314). "Very pleased with these muffs". Covers ears well.	No. 9 shaft, 4300 level. No. 152 stope.
2	Ball Mill Operator Area (D. McPhee)	◒	14	87.8	>7.7	>7.8	>7.8	94	>8.2	14.8	>11.5	94.4	95.5	108.9		Mill.
3	Flotation Operator Area (D. McPhee)	◒	14	-	-	-	-	88.4	>7.09	>12.7	>9.89	87.6	85.9	99.3	Invalid test. Dosimeter malfunction.	Mill.
4	Converter Skimming - Fluxing (D. McPhee)	◒	14	87.9	6.3	8.3	>7.3	88.9	>13.5	4.07	>8.78	85.2	87.5	99.8		Smelter.
5	Converter Punchers (D. McPhee)	◒	14	97.6	>17.6	>17.5	>17.6	99.3	>16.3	>6.13	>12.2	98.4	98.4	115.7		Smelter.
	Mean		14	92.38	-	-	-	94.22	-		-	93.88	94.32	108.1		
	Std. Dev.		-	5.26	-	-	-	5.65	-	-	-	7.65	7.67	8.44		

Note: ○ Satisfactory, ◒ Good, ● Very good

Undetermined numbers (> No.) are not in Mean value.

L(MAX) AND L(PEAK) LEVELS

Using Appendices A to F, measurement results were calculated for L(max) and L(peak) levels (Table G-1). The aim was to see how big the "peaks" are, which according to some authorities, influence loss of hearing (2). Measurements were made with an integrating sound level meter, B and K, type 2225. Instrument control was performed to find means of standard deviation for L(max) and L(peak). Results were approximately the same. This method of control is used during field measurements. The confidence limits of results were:

90% Confidence Limit		95% Confidence Limit	
L(max)	L(peak)	L(max)	L(peak)
3.16 to 5.86 dBA	3.81 to 6.19 dBA	2.85 to 6.17 dBA	2.60 to 7.4 dBA

From this information we can see how precise the measurements were.

Table G-1 - Peak levels in mining, milling and smelting operations at Falconbridge and Strathcona mines.

Falconbridge - Strathcona

Instrument: Bruel and Kjaer Integrating Sound Level Meter
Type 2225.

No.	Sound Source	dBA		Δ	N
		L_{max}	L_{peak}		
		Mean Std. Dev.	Mean Std. Dev.		
1	Jack Leg Drill	118.65 3.36	134.85 5.68	16.3	11
2	Stoper Drill - Rock Bolter	118.51 5.92	135.0 7.0	16.5	22
3	Jumbo Drill - two booms	116.96 5.91	122.14 5.91	15.19	8
4	Long Hole Drill	119.19 1.98	135.08 2.59	15.89	4
5	Long Tom Drill - two booms	120.27 2.99	137.17 4.63	16.9	23
6	ITH In the Hole Drill	98.27 5.12	116.25 5.66	17.98	7
7	Diamond Drill	104.02 4.76	120.81 9.93	16.79	7
8	Mucking Machine	106.58 3.60	121.53 3.53	14.95	4
9	Bolting Machine	-	-	-	-
10	Air Plugger (Brk. Cement)	-	-	-	-
11	Slusher	97.50 4.99	111.35 4.45	13.85	6
12	Scooptram	106.55 14.57	123.33 11.80	16.78	12
13	Conveyor Man	94.83 6.40	112.15 8.35	17.32	3
14	Chute Puller	114.80 9.19	133.15 3.32	18.35	2
15	Vent. Fan - 38" 60 HP	-	-	-	-
16	Primary Crusher - U/G Jaw Crush.	102.34 6.93	121.56 8.24	19.22	8
17	Secondary Crusher	91.77 1.33	106.27 1.62	14.5	3
18	Tertiary Crusher	95.65 0.21	108.35 0.64	12.9	2
19	Ball Mill	93.20 2.02	107.57 1.16	14.37	3
20	Flotation Op. Area	85.9	99.3	13.4	1
21	Compressor Room	89.7	103.0	13.3	1
22	Power House	94.5	107.5	13.0	1
23	Electrostatic Precipitator	93.65 0.35	109.20 3.82	15.55	2
24	Converter Puncher	99.13 1.10	114.27 1.79	15.14	3
25	Converter Skimmer - Fluxing	89.47 4.75	103.83 4.91	14.36	3

	Mean$_{SD}$ Std.Dev.	Mean$_{SD}$ Std.Dev.	
	4.51	5.00	
◇ 19	3.45	3.04	19 ◇

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Attenuation measurements of ear muffs at Lockerby Mine, 1984

1986

ATTENUATION MEASUREMENTS OF EAR MUFFS AT LOCKERBY MINE 1984

by

M.U. Savich* and J.K. Weglo**

ABSTRACT

Ear muffs are the main protection of the mining workforce for the attenuation of noise.

The measurement of head size as against clamping force as well as the condition of the ear muffs are demonstrated as important variables in the attenuation of noise.

The "NO NOISE" ear muff attenuation was about 12.5 dBA as an average with Standard Deviation of about 4 to 6 dBA depending on the use of the ISO or OSHA made at the Lockerby Mine.

The Mark V ear muffs, replacing those in the study, based on clamping force measurements versus head size can be expected to produce attenuation >14 dBA.

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MESURE DE L'EFFICACITÉ DES CASQUES ANTIBRUIT À ATTÉNUER LE BRUIT À LA MINE LOCKERBY 1984

par

M.U. Savich* et J.K. Weglo**

RÉSUMÉ

Les casques antibruit sont la principale source de protection contre le bruit pour les travailleurs miniers.

La mesure de la taille de la tête par rapport à la force de serrage ainsi que l'état des casques antibruit sont indiqués comme étant d'importantes variables de l'atténuation du bruit.

Lors de l'étude à la mine Lockerby, le niveau d'atténuation du bruit "NO NOISE" des casques antibruit était d'une moyenne d'environ 12,5 dBA avec un écart type d'environ 4 à 6 dBA suivant l'utilisation ISO ou OSHA.

Cependant, d'après les mesures de la force de serrage par rapport à celles de la taille de la tête, les casques antibruit Mark V qui ont remplacé les casques utilisés dans cette étude pourraient assurer une atténuation du bruit de >14 dBA.

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INTRODUCTION

As part of the ongoing program of abating noise pollution at all Falconbridge Mines measurements were taken to test the efficiency of ear muffs which were being used. Most of the analyses were done on "NO NOISE" ear muffs, model NN3-F because they were the ones used by 95% of the workforce.

The following ear muffs were tested at the Lockerby Mine:

1) "NO NOISE", model NN3-F, the Hellberg Standard Volume Hearing Protector, hard hat attachment;
2) Mark IV, MSA, worn behind the head;
3) Peltor H7P3e hard hat attachment;
4) David Clark, model E-705, hard hat attachment;
5) Racal.

Forty-six tests of head size and clamping force, and 21 attenuation tests were performed on the "NO NOISE" ear muffs. On the Mark IV muffs 7 tests of attenuation were done, while only one such test was performed on each of the other brands.

The framework and method as well as theoretical and practical considerations are outlined in the main report which should be read to compare Lockerby results with other Falconbridge Mines.

Attenuation characteristics and noise reduction ratings (NRR) given in Table 1 are those which were supplied by manufacturers. From these manufacturers' ratings it appears that all muffs provide relatively equal attenuation.

MEASUREMENTS AND RESULTS

Tests were performed using Metrosonics instrument, type db-307. This instrument measures sound over the continuous range of 45 to 140 dBA. Its

Table 1 - Attenuation characteristics of ear muffs acquired for testing (ANSI S3.19-1974)

No.	Ear Muff	Characteristic	Frequency Hz									NNR
			125	250	500	1000	2000	3150	4000	6300	8000	
1	"NO NOISE" Model NN3- Hellberg	Mean	16.2	19.9	25.2	34.1	36.0	39.2	39.0	40.3	38.1	24
		Std. Dev.	2.5	1.8	2.0	1.7	2.2	3.1	2.0	4.0	4.1	
2	Mark IV MSA	Mean	17.0	18.0	29.0	36.0	38.0	44.0	44.0	43.0	43.0	24
		Std. Dev.	2.6	2.6	3.1	3.2	4.1	7.2	4.6	4.7	5.7	
3	Peltor H7P3e	Mean	14.1	18.8	28.1	36.2	35.6	38.4	35.0	35.5	36.4	24
		Std. Dev.	2.1	2.0	3.0	2.1	2.2	2.3	2.1	2.1	2.4	
4	David Clark Model E-705	Mean	12.0	17.0	30.0	35.0	35.0	36.0	37.0	32.0	30.0	24
		Std. Dev.	2.5	3.0	4.6	5.6	4.5	4.3	4.2	4.1	2.9	
5	Racal	Mean	-	-	-	-	-	-	-	-	-	-
		Std. Dev.										

microprocessor continuously samples and displays dBA sound levels while calculating L_{max}, L_{peak} and test duration. Testing should be done using 4 dosimeters rather than 3, as we have done. This would simplify and speed up the testing time. It is very time-consuming and difficult to reset from OSHA (doubling at 5 dB) to ISO (doubling at 3 dB) in most work areas.

Cables and microphones should be small in size to avoid creating an opening that would cause leakage of sound at the point where they enter the muff (breaking the seal between muff and face). It was very difficult at times to position microphones comfortably inside ear muffs. Workers had a tendency to want to adjust their ear muffs while the test was being conducted, which sometimes caused leakage and forced us to repeat the test.

Conducting tests on workers using fixed equipment (such at ITH in-the-hole drills, jumbo drills, and diamond drills) were simpler to perform providing workers had no problems with their equipment and were willing to cooperate. Testing where workers use man-handling equipment, such as jack legs - stopers, scooptrams and mucking machines were more difficult.

The head size was measured with outside calipers, and clamping force with a manual balance.

HEAD SIZE AND CLAMPING FORCE

Head size and clamping force tests were performed on "NO NOISE" ear muffs, Mark IV muffs, David Clark muffs and Peltor muffs (Appendices A and B).

A symmetrical frequency, or bell-shaped curve was constructed on the basis of 64 head size tests (Figure 1). Previously, two frequency curves were constructed: a leptokurtic curve on the basis of a small population of 18 for attenuation tests; and a negatively skewed curve on the basis of a population of 46. Only on the basis of surveying a large population can precise results

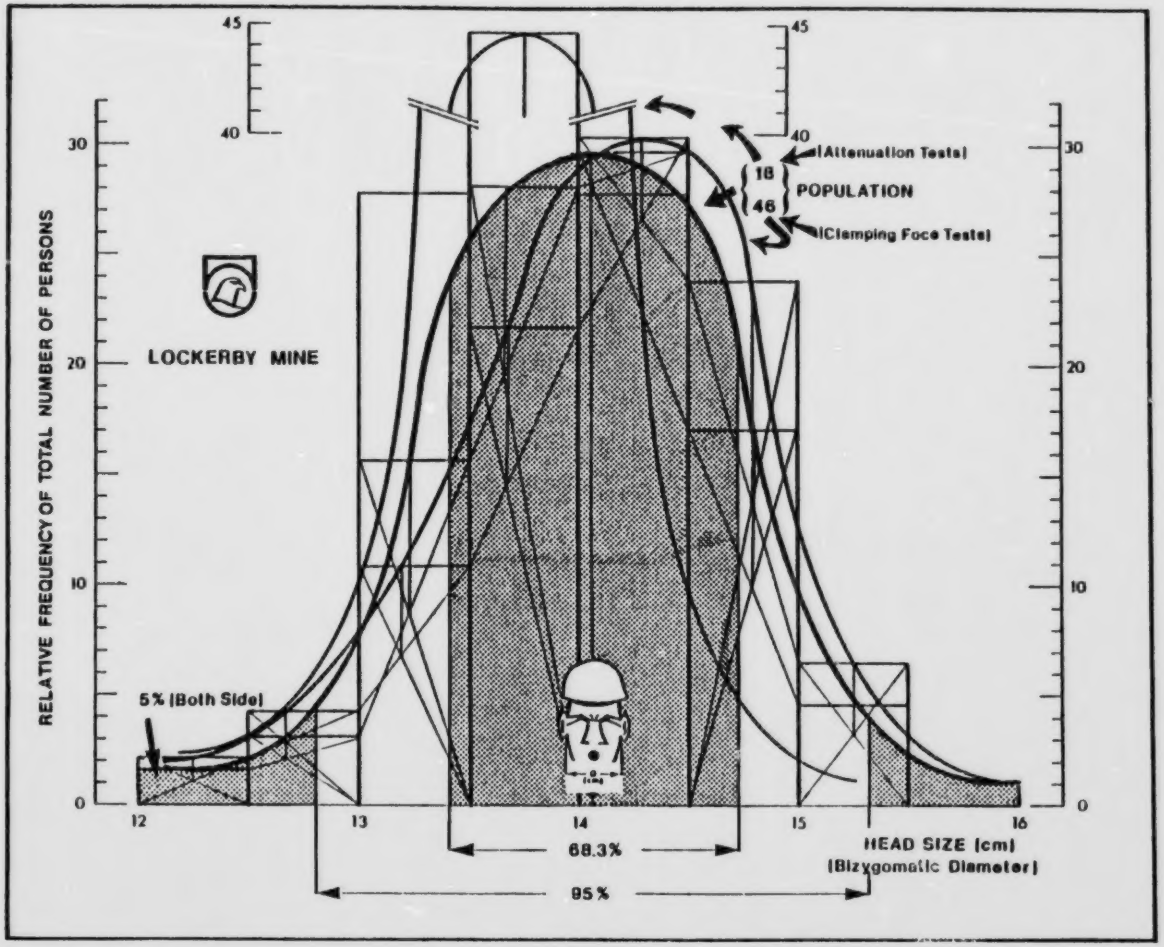

Fig. 1 - The symmetrical frequency or bell-shaped curve of head size tests (population 64).

be obtained. By simply calculating the above-mentioned curve nuances cannot be noticed (Table 2).

Table 2 - Summary of head size tests

No.	Test	N	Mean	Std. Dev.	Confidence Limit 90%	Confidence Limit 95%
1	Head size and clamping force "NO NOISE"	46	13.96	0.72	13.96±0.17	13.96±0.21
2	Head size and clamping force - different muffs	16	14.00	0.70	14.00±0.31	14.00±0.37
3	Attenuation	18	13.64	0.33	13.64±0.13	13.64±0.16
1-3	Σ	80	13.90	0.65	13.90±0.10	13.90±0.12

Population → N; Grand Mean → 13.90

In this Table we can see that confidence limits are high, and that at Lockerby heads with normal bizygomatic diameters are prevalent (for North America the average head size is 14.35 cm).

A frequency curve was constructed from clamping force data (Figure 2). This bimodal frequency curve has two maxima: the first maximum at 600 (gwt) is related to a group with markedly small heads; the second maximum is at 1350 (gwt). From the clamping force versus population bar graph in Figure 2, relative symmetry is observable over the interval 900 to 1800 (gwt). Good attenuation would be expected in this range. To give substance to this assertation a bar graph was constructed from "NO NOISE" muff measurements of population -46 (Figure 3). The largest negative deviation, as well as the most rapid rate of ear muff deterioration, occurs for head sizes from 13.00 to 13.50 cm. Such is also the case at other mines. All other results are acceptable. Clamping force increases with head size.

Data from Appendix A was used to construct a standard deviation (error) ellipse (Figure 4). The ellipse largely covers the field of head size versus

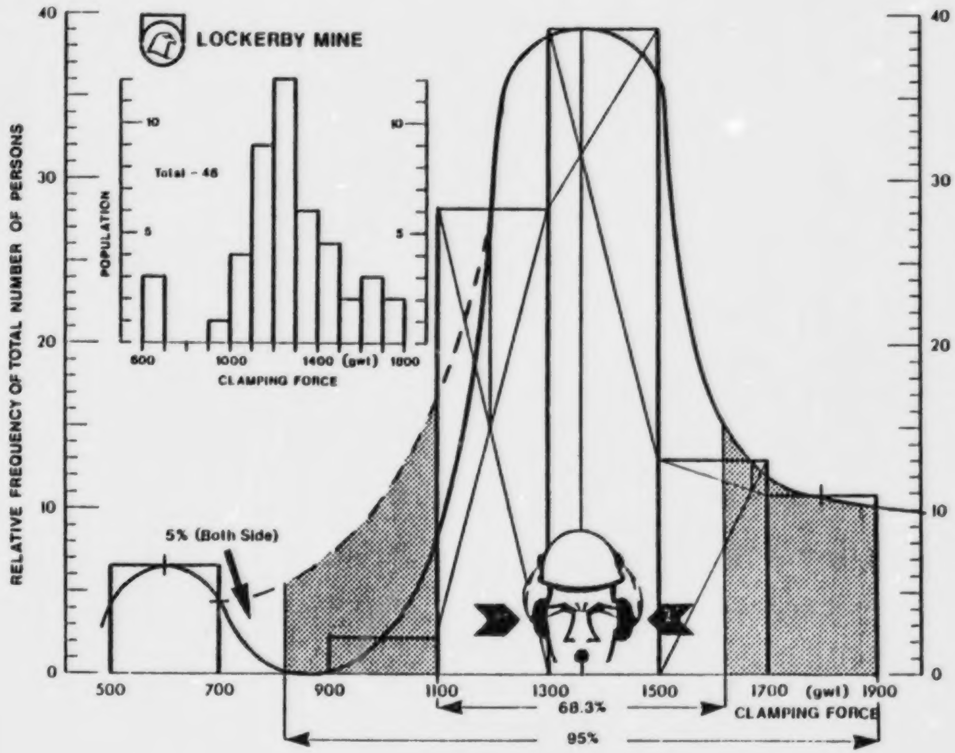

Fig. 2 - The bimodal frequency curve has two maxima: the first maximum is at 600 (gwt); and the second at 1350 (gwt).

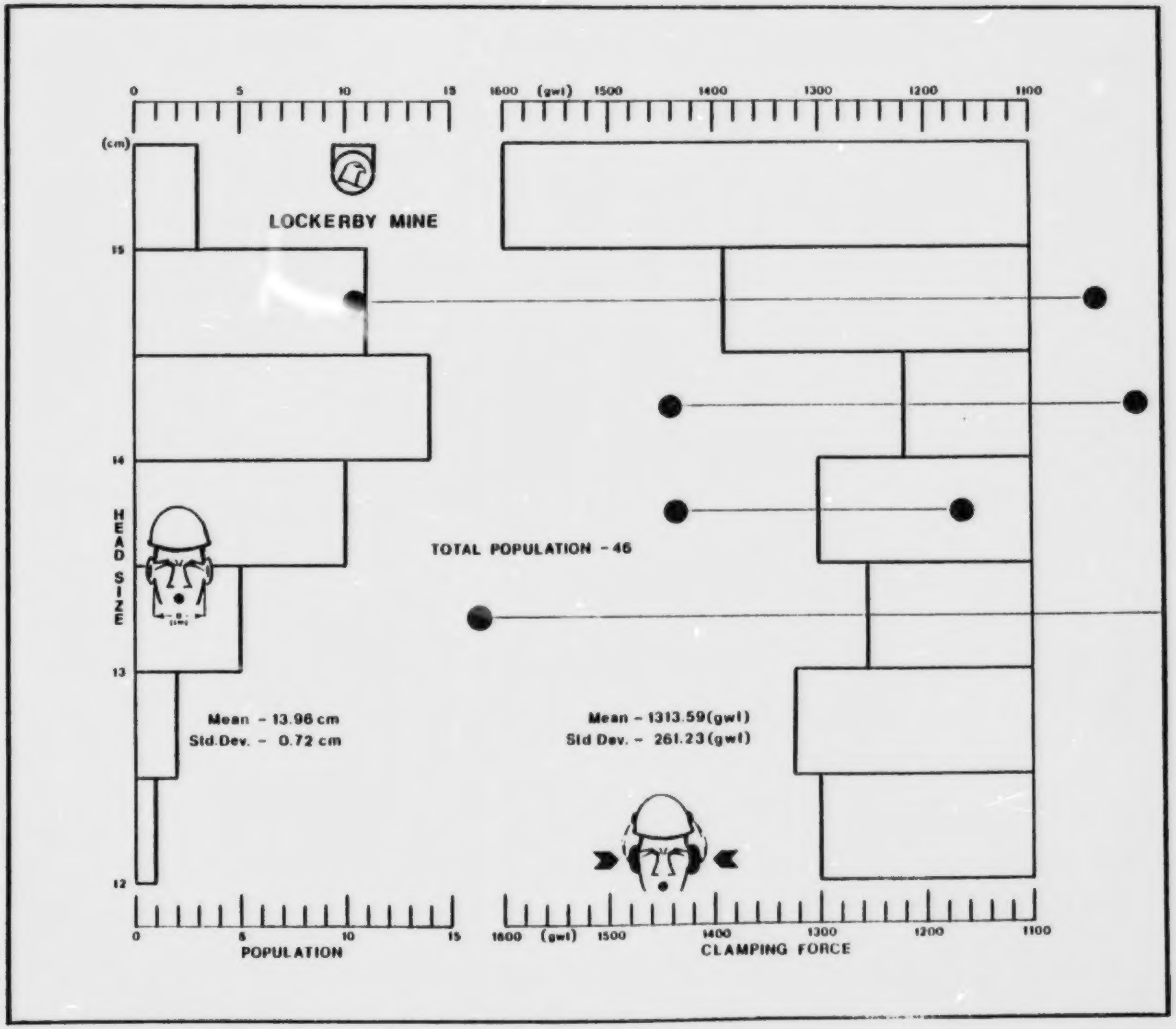

Fig. 3 - Relationships between head size and clamping force at the Lockerby Mine.

clamping force measured, and we can therefore expect good attenuation.

Utilization of OSHA prescribed methods of estimating the adequacy of hearing protector attenuation requires the availability of the manufacturer's published Noise Reduction Rating (NRR) and/or octave band attenuation data at frequencies ranging from 125 Hz to 8 kHz (1). This estimation method is the one which is used in all reports evaluating the Noise Exposure. We will compare NRR with our measurements to show the difference between estimated and actual values. Table 3 shows 30.6% of ear muff conditions were fair to poor. Nineteen percent of the ear muffs were in fair condition, while 11% were poor. We should expect attenuation to be poorer than rated.

Table 3 - Tests of ear muff conditions in the mine

No.	Ear Muff	N*	Ear Muff Conditions					
			Good		Fair		Poor	
			N_1	Percent	N_2	Percent	N_3	Percent
1	"NO NOISE" NN3-F	46	33	71.74	7	15.22	6	13.04
2	Mark IV MSA	13	8	61.54	4	33.77	1	7.92
3	David Clark, model E-705 Straightaway	2	2	100.00	0	0.00	0	0.00
4	Peltor H7P3e	1	0	0.0	1	100.00	0	0.00
1-4	Σ	62	43	69.35	12	19.35	7	11.29

Note: * Population ($N^* = N_1 + N_2 + N_3$)

While tests were being performed, ear muffs in fair to poor condition were maintained or replaced. Interestingly, ear muff clamping force was good overall at Lockerby, which was the last mine at which measurements were taken. Surveyors by then developed a routine, were more experienced and precise, and better evaluated ear muff conditions.

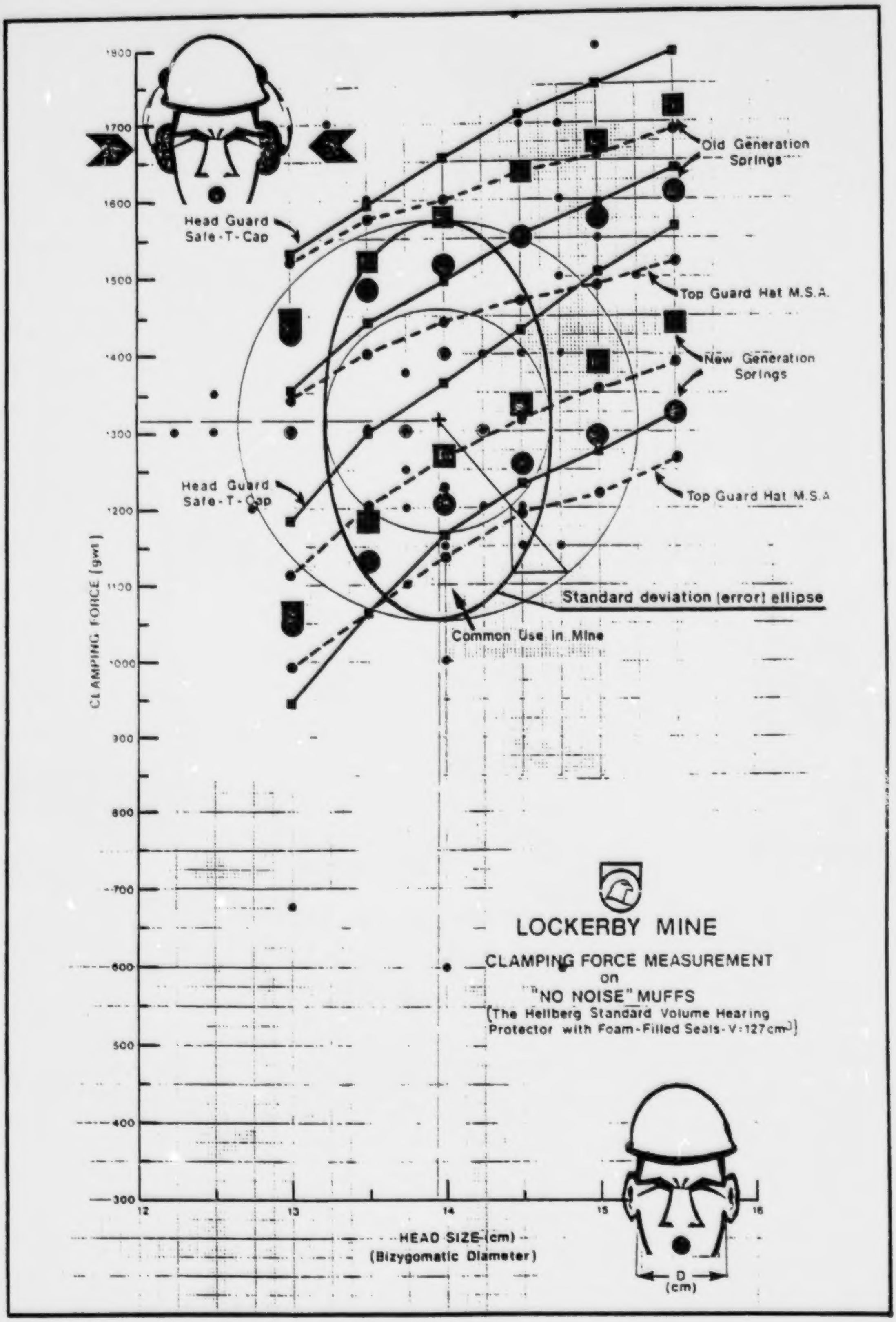

Fig. 4 - Standard deviation (error) ellipse of "NO NOISE" muffs.

ATTENUATION MEASUREMENTS

Attenuation measurements were performed on the following ear muffs:

1) "NO NOISE", model NN3-F, 10 measurements in OSHA mode (Appendix C) and 21 measurements in ISO mode (Appendix D);
2) Mark IV, MSA, 7 measurements in OSHA mode (Appendix C), and 7 measurements in ISO mode (Appendix E);
3) Peltor H7P3e, 1 measurement in ISO mode (Appendix E);
4) David Clark, model E-705, 1 measurement in OSHA mode (Appendix C), and 1 measurement in ISO mode (Appendix E);
5) Racal, 1 measurement in OSHA mode (Appendix C), and 1 measurement in ISO mode (Appendix E).

Testing was carried out at various types of equipment (e.g., Joy jack-legs and stopers, long-hole drills, in-the-hole ITH drills, diamond drills, slushers and scooptrams). A total of 19 tests in the OSHA mode, and 31 in the ISO mode were conducted.

Tests of "NO NOISE" ear muffs revealed the following attenuations (Appendices C and D):

Mode	dBA		Confidence Limit	
	Mean	Std. Dev.	90%	95%
OSHA	12.86	5.86	12.86±3.46 dBA	12.86±4.22 dBA
ISO	12.02	4.30	12.02±1.59 dBA	12.02±1.93 dBA

In both modes we get results which vary markedly. The most likely explanation of this variation in the OSHA mode is because of the small population. Results of other ear muffs are entered in the Appendices, but are not discussed because they were obtained on very small populations. The reason for the small number of measurements is the lack of time for performing them, which was exacerbated by frequent instrument malfunctions.

At the Lockerby Mine almost 95% of the miners wear "NO NOISE" ear muffs, which have a smaller cup size. Workers with large ears find microphones in their muffs very annoying and claim that they cause an increase in noise levels. When positioning a microphone in the ear muff it is very important to take a noise reading (trial run) and readjust if necessary. Workers should be instructed not to adjust their muffs until the test has been completed. At times when a worker is working hard physically (lots of bending and reaching) in operating his equipment, adjustment is more frequent and more leakage occurs. Other muffs, such as Mark IV (Type 2), David Clark (Type 3), Peltor (Type 4), and Racal (Type 5), have a large cup, which should help avoid this problem. Indications are that measured attenuations of Types 2 to 5 muffs are poorer, as documented below:

N*	Mode	dBA		Confidence Limit	
		Mean	Std. Dev.	90%	95%
8	OSHA	9.96	7.31	9.96±4.60 dBA	9.96±6.07 dBA
10	ISO	10.96	8.22	10.86±4.91 dBA	10.86±5.92 dBA

Note: *Population

From these results it can be seen that the lower attenuation limit is too low at 5-6 dBA, while the higher limit is too high at 15-17 dBA according to the OSHA and EPA prescribed methods of estimating adequacy of hearing protector attenuation. This is because these ear muffs have the same NNR assigned as the "NO NOISE" muffs.

Comfort received better marks at Lockerby than in all the other Falconbridge mines. Only at Lockerby did comfort go hand in hand with clamping force. Comfort test results are given in Table 4.

Table 4 - Comfort of ear muffs in the mines

No.	Ear Muff	N*	○-Satisfactory		◒-Good		● -Very Good	
			N_1	Percent	N_2	Percent	N_3	Percent
1	"NO NOISE" NN3-F	23	11	47.8	7	30.4	5	21.7
2	Mark IV MSA	6	0	0.0	6	100.0	0	0.0
3	Peltor H7P3e	1	0	0.0	0	0.0	1	100.0
4	David Clark Model E-705	2	1	50.0	1	50.0	0	0.0
5	Racal	1	1	100.0	0	0.0	0	0.0
1-5	Σ	33	13	39.4	14	42.4	6	18.2

Note: * Population ($N^* = N_1 + N_2 + N_3$)

From these results it can be concluded that 60.6% of the workers deemed comfort to be good to very good. The cause of the positive clamping force/comfort relationship could not be found.

Using data from Appendices C, D and E, and Fraser Mine measurements, L_{max} and L_{peak} levels were calculated and were then compared with measurement results at Falconbridge and Strathcona Mines (Table 5). Measurements at Falconbridge and Strathcona were carried out with an integrating sound level meter, B and K, type 2225, whereas measurements at Fraser and Lockerby Mines were taken with a Metrosonics db-307 instrument. Instrument control was done to find means of standard deviations of L_{max} and L_{peak} (accuracy of instrument field test).

The results should be approximately the same, however, Lockerby and Fraser Mines' results differ considerably by 7 dBA. Calculating the L_{peak} from these measurements and drawing conclusions based on them would be inadvisable.

Table 5 - Peak levels in mining operations at the Falconbridge mines.

		Falconbridge - Strathcona Instrument: Bruel and Kjaer Integrating Sound Level Meter Type 2225.				Fraser - Lockerby Instrument: Metrosonics db-307 Noise Dosimeter and Integrating Sound Level Meter.				
		dBA				dBA				
		L_{max}	L_{peak}			L_{max}	L_{peak}			
No.	Sound Source	Mean Std. Dev.	Mean Std. Dev.	Δ	N	Mean Std.Dev.	Mean Std.Dev.	Δ	N	Comments
1	Jack Leg Drill	118.65 3.36	134.85 5.68	16.3	11	121.43 2.35	148.0 0.0	26.6	9	In $Mean_{SD}$, value not included
2	Stoper Drill - Rock Bolter	118.51 5.92	135.0 7.0	16.5	22	118.48 1.65	141.92 6.22	23.4	18	
3	Jumbo Drill - two booms	116.96 5.91	122.14 5.91	15.19	8	109.02 1.03	136.85 10.47	27.8	15	
4	Long Hole Drill	119.19 1.98	135.08 2.59	15.89	4	116.06 2.79	141.12 6.87	25.06	5	
5	Long Tom Drill - two booms	120.27 2.99	137.17 4.63	16.9	23	-	-	-	-	
6	ITH In the Hole Drill	98.27 5.12	116.25 5.66	17.98	7	101.06 5.79	121.65 18.36	20.59	37	
7	Diamond Drill	104.02 4.76	120.81 9.93	16.79	7	108.6 1.77	133.74 11.90	25.14	18	
8	Mucking Machine	106.58 3.60	121.53 3.53	14.95	4	109.97 0.51	147.26 1.18	37.29	5	
9	Bolting Machine	-	-	-	-	110.55	147.0	36.4	1	
10	Air Plugger (Brk. Cement)	-	-	-	-	112.20 0.57	148.0 0.0	35.8	2	In $Mean_{SD}$, value not included
11	Slusher	97.50 4.99	111.35 4.45	13.85	4	115.30 1.27	148.0 0.0	32.7	2	In $Mean_{SD}$, value not included
12	Scooptram	106.55 14.57	123.33 11.80	16.78	12	108.18 5.22	142.12 9.38	33.94	16	
13	Conveyor Man	94.83 6.40	112.15 8.35	17.32	3	-	-	-	-	
14	Chute Puller	114.80 9.19	133.15 3.32	18.35	2	-	-	-	-	
15	Vent. Fan - 38" 60 HP	-	-	-	-	100.48 5.10	117.91 14.12	17.43	4	
16	Primary Crusher - U/G Jaw Crush.	102.34 6.93	121.56 8.24	19.22	8					
17	Secondary Crusher	91.77 1.33	106.27 1.62	14.5	3					
18	Tertiary Crusher	95.45 0.21	108.35 0.64	12.9	2					
19	Ball Mill	93.20 2.02	107.57 1.16	14.37	3					
20	Flotation Op. Area	85.9	99.3	13.4	1					
21	Compressor Room	89.7	103.0	13.3	1					
22	Power House	94.5	107.5	13.0	1					
23	Electrostatic Precipitator	93.65 0.35	109.20 3.82	15.55	2					
24	Converter Puncher	99.13 1.10	114.27 1.79	15.14	3					
25	Converter Skimmer - Fluxing	89.47 4.76	103.83 4.91	14.36	3					

Fraser - Lockerby:

	$Mean_{SD}$ Std.Dev.	$Mean_{SD}$ Std.Dev.	
◇8	2.98 2.09	9.81 5.25	8◇

Falconbridge - Strathcona:

	$Mean_{SD}$ Std.Dev.	$Mean_{SD}$ Std.Dev.	
◇19	4.31 3.45	5.00 3.04	19◇

Laboratory tests of instrument accuracy done at Laval University came to the same conclusion (2). This was the reason why L_{max} and L_{peak} measurements at Fraser and Lockerby were not presented in the main report prepared for Falconbridge Ltd.

CONCLUSION

Measurements have shown that the attenuation of "NO NOISE" ear muffs was about 12.5 dBA. Ear muff efficiency is dependent on the frequency range of noise. Overall, the condition of ear muffs was satisfactory, but it should be noted that 11% of the ear muffs were in poor shape (Table 3). The safety department must continue to work diligently in maintaining and replacing ear muffs while the workers continue to be properly trained in correctly fitting ear muffs. Head shapes and sizes had a marked effect on attenuation, as did physical obstructions (e.g., eye glasses, ear size) that weaken attenuation. From the data we can conclude that ear muffs in themselves are not a complete solution to the attenuation of the noise level in the mining environment.

Ear muff control should be continued by measuring head size and clamping force with the apparatus suggested in the main report for better attenuation.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the help and cooperation of E. Isaacs, Director, and P. Savalas, Field Technicial of M.A.P.A.O, as well as the Senior Mine Supervisor, T. Lakanen, Lockerby Mine, and Dr. A.G. Cecutti, Medical Director, D. McPhee, and R. Desjardins, Technician, Falconbridge Ltd.

Acknowledgement is also extended to J. Vergunst, Working Environment Engineer, Ontario Ministry of Labour, Sudbury, and R. Pleasance, Branch Manager, Levitt-Safety Ltd. (Metrosonics Inc.), Sudbury, Ontario for the loan

of the instruments.

Thanks are extended to G. Knight, Research Scientist, Elliot Lake Laboratory, for reviewing the manuscript and making numerous helpful suggestions.

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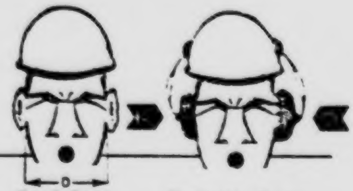
1. EPA. "Noise labeling requirements for hearing protectors"; Fed Regist 42(190), 40 CFR Part 211, 56139-56147; 1979.

2. Archambault, R., Private communication; 1985.

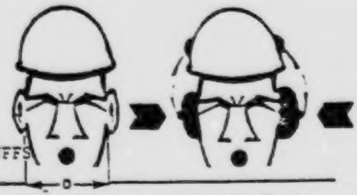
Head size and clamping force data of "NO NOISE", model NN3-F ear muffs.



No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Driller	2	14.00	1150
2	Driller	1	14.00	1000
3	Driller	1	14.25	1300
4	Driller	1	12.75	1200
5	Driller	2	14.00	1400
6	Driller	1	15.00	1300
7	Driller	1	13.00	1300
8	Driller	1	13.00	1300
9	Driller	1	14.50	1250
10	Driller	1	13.00	675
11	ITH Driller	1	12.50	1350
12	ITH Driller	1	14.75	1150
13	ITH Driller	1	14.75	1500
14	Drift Leader	1	15.00	1500
15	Drift Leader	1	14.00	1200
16	Drift Leader	1	14.75	1600
17	Drift Leader	1	14.50	1150
18	Longhole Driller	1	14.00	1300
19	Spare Man	1	14.00	1400
20	Spare Man	1	13.50	1400
21	Blaster's Helper	3	14.75	600
22	Chute Blaster	1	14.25	1300
23	Motorman	3	14.00	600
24	Trammer	3	12.50	1300
25	Scooptram	1	12.25	1300
26	Scooptram	1	13.75	1300
27	Scooptram	2	13.00	1300
28	Scooptram	2	13.75	1200
29	Scooptram	1	14.75	1700
30	Scooptram	1	14.50	1850
31	Scooptram	1	13.75	1100
32	Scooptram	2	14.00	1200
33	Mechanic	1	14.50	1400
34	Mechanic	1	14.25	1400
35	Mechanic	3	13.75	1300
36	Mechanic	1	14.00	1200
37	Mechanic	3	14.00	1225
38	Mechanic	2	14.75	1400
39	Mechanic	1	13.75	1250
40	Mechanic	2	14.50	1700
41	Electrician	1	13.50	1600
42	Level Cleaner	1	15.25	1500
43	Level Cleaner	3	13.25	1700
44	Level Cleaner	1	13.50	1300
45	Level Cleaner	1	13.75	1375
46	Shift Boss	1	14.25	1200
	Mean:		13.96	1313.59
	Std. Dev.:		0.72	261.23

Note: 1 - Good; 2 - Fair; 3 - Poor.

Head size and clamping force data of different muffs:
Mark IV, MSA; David Clark, Model E-705; Straightaway; and Peltor H7P3e



MARK IV MUFFS

No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Driller	1	13.75	1700
2	Driller	2	13.50	1700
3	Driller	2	13.00	1450
4	Driller	2	15.00	1100
5	Driller	1	13.75	1300
6	Driller	1	14.50	1550
7	Drift Leader	1	14.50	1200
8	Drift Leader	1	14.25	1000
9	Raise Leader	1	14.00	1200
10	Raise Leader	1	14.00	1200
11	Cage Tender	2	15.00	1000
12	Cage Tender	1	15.25	1525
13	Cage Tender	3	14.50	550
	Mean:		14.25	1313.46
	Std. Dev.:		0.65	339.82

DAVID CLARKE MUFFS

No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Level Cleaner	1	14.00	500
2	Vent. Foreman	1	14.00	1400

PELTOR (H7)

No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Electrician	2	13.00	600

Σ	Mean:	14.00	1290.32
	Std. Dev.:	0.70	303.04

Note: 1 - Good; 2 - Fair; 3 - Poor.

Attenuation tests of "NO NOISE" model NN3-F; Mark IV, MSA;
David Clark, model E-705; and Racal ear muffs in the OSHA mode.

No.	Equipment	Comfort		L. Avg. (dBA)	Attenuation (dBA)			L. Max (dBA)	Attenuation (dBA)			L. Peak (dBA)	Attenuation (dBA)			Comments	Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.		L.S.	R.S.	B.S.		
								EAR MUFF - "NO NOISE"									
1	2 Jack Leg Drill AL-60	○	13.25	119.0	15.3	12.5	13.9	126.5	17.1	13.4	15.3	148.0	9.8	9.0	9.4	Both arms bent	3100 Level
2	2 Jack Leg Drill AL-60	○	-	118.7	12.1	9.6	10.8	120.9	6.2	8.1	7.2	148.0	12.3	13.4	12.9		1700 Level
3	Long Hole Drill	○	13.25	104.9	3.0	2.1	2.5	114.7	5.5	5.1	5.3	147.8	14.7	15.1	14.9	Adjust. screw missing on muffs	1800 Level
4	ITH-In the Hole Drill	○	13.75	114.8	5.5	18.3	11.9	118.9	11.8	19.2	15.5	148.0	17.4	24.2	20.8	Left arm on muff bent	3100 Level
5	ITH-In the Hole Drill	◒	14.0	101.8	23.8	23.1	23.5	103.1	7.6	11.2	8.9	148.0	4.9	23.3	14.1		3100 Level
6	Diamond Driller	◒	13.75	101.2	9.7	19.7	14.7	107.3	11.2	19.2	15.2	145.8	22.5	19.0	20.8	Left arm on muff bent	1700 Level
7	Diamond Driller-Helper	○	13.50	104.4	19.8	16.6	18.2	107.8	20.0	17.0	18.5	148.0	27.4	25.0	26.2		1700 Level
8	Air Slusher	○	13.25	110.7	23.6	8.2	15.9	114.4	22.4	10.7	16.5	148.0	27.5	25.2	26.4		3100 Level
9	Scooptram ST5	○	14.0	102.9	5.4	8.7	7.0	108.6	4.1	5.7	4.9	148.0	24.5	16.0	20.2	Adjust. screw missing on muffs	1800 Level
10	Scooptram JS500	○	-	98.6	10.2	10.2	10.2	114.8	19.4	18.6	19.0	148.0	17.6	6.4	12.0		3600 Level
	Mean		13.59	107.9	12.84	12.92	12.86	113.50	12.53	12.72	12.67	147.75	17.86	17.65	17.77		
	Std. Dev.		0.33	7.16	7.56	6.43	5.86	6.77	6.74	5.54	5.47	0.69	7.61	6.80	5.95		
								EAR MUFF - MARK IV									
1	2 Jack Leg Drill AL-60	-	13.5	116.0	6.1	10.2	8.1	122.8	7.2	10.9	9.0	148.0	6.5	8.7	7.6		1100 Level
2	2 Joy Stopers-Rock Bltg.	○	13.0	110.2	1.5	3.3	2.4	119.2	9.0	4.9	6.9	148.0	10.6	12.4	11.5	Cushions bad shape, not worn	1800 Level
3	Stoper Driller Rock Bltg	○	-	108.0	13.1	11.1	12.1	118.8	14.7	11.9	13.3	148.0	22.0	15.9	19.0	Muffs not adjusted properly	-
4	ITH-In the Hole Drill	○	13.75	102.8	9.0	8.5	8.7	103.7	7.0	7.8	7.4	148.0	27.5	28.0	27.8	Left arm on muff bent	1700 Level
5	ITH-In the Hole Drill	○	13.75	100.3	23.0	21.6	21.3	103.2	17.9	13.9	15.9	148.0	20.1	28.0	24.0		3100 Level
6	Diamond Driller	○	14.00	102.9	3.1	14.3	8.7	107.6	6.3	12.1	9.2	148.0	28.0	28.0	28.0	Cushions bad shape, bent arms	1700 Level
7	Scooptram ST2	○	13.50	97.5*	12.1*	11.0*	11.5*	108.1*	3.1*	10.8*	1.15*	148.0*	15.4*	11.8*	13.6*	Cushions bad shape, not worn	2600 Level
	Mean		13.58	106.70	9.30	11.81	10.55	112.55	10.35	10.25	10.28	148.0	19.12	20.17	19.65		
	Std. Dev.		0.34	5.85	7.90	6.81	6.99	8.70	4.80	3.30	3.56	0.0	8.81	8.88	8.57		
								EAR MUFF - DAVID CLARK									
1	Diamond Driller	○	14.0	106.2	19.9	12.2	16.0	108.4	18.9	9.3	14.1	148.0	28.0	28.0	28.0	Right arm on muff bent	1700 Level
								SAFETY MUFFS - RASCAL									
1	Scooptram ST500 (Rem.Con)	C	13.25	96.3	[illegible]	0.6	0.4	110.9	4.2	1.1	2.6	148.0	15.2	15.4	15.3	No adjustment on left	1100 Level

Note: ○ Satisfactory; ◒ Good; ● Very Good.

* In mean value not included.

Attenuation tests of "NO NOISE" model NN3-F in the ISO mode

No.	Equipment	Comfort		I. Avg. (dBA)	Attenuation (dBA)			I. Max (dBA)	Attenuation (dBA)			I. Peak (dBA)	Attenuation (dBA)			Comments	Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.		L.S.	R.S.	B.S.		
1	Jack Leg Drill AL-60	○	-	116.7	12.0	14.6	13.3	118.8	9.7	13.3	11.5	148.0	16.0	17.7	16.9		-
2	Stoper Drill Rock Bltg.	●	-	116.7	18.5	20.3	19.4	120.2	18.6	21.1	19.9	136.8	13.2	13.5	13.4		3100 Level
3	Stoper Drill-Rock Bltg.	●	-	113.0	16.3	1.2	8.7	120.1	0.4	15.5	7.9	139.5	11.8	11.6	11.7		3300 Level
4	Long Hole Drill	○	13.25	111.5	9.6	12.2	10.9	115.5	7.1	16.9	12.0	148.0	16.4	22.9	19.7	Adjust. screw missing on muffs	1800 Level
5	Long Hole Drill	○	13.5	118.7	16.1	18.7	17.4	118.7	10.4	17.9	14.1	140.3	16.3	11.6	13.9	Left arm on muff bent	3100 Level
6	Long Hole Drill	◒	-	112.4	14.9	18.2	16.5	112.4	16.0	16.3	16.15	132.0	9.2	11.6	10.4		3100 Level
7	Long Hole Drill	◒	-	119.0	6.2	7.3	6.7	119.0	2.4	[illegible]	4.1	117.5	2.0	2.2	2.1		3300 Level
8	ITH-In the Hole Drill	◒	13.5	101.9	16.6	20.0	18.3	102.3	[illegible]	15.8	16.1	148.0	27.8	26.3	27.1		3100 Level
9	ITH-In the Hole Drill	●	-	98.3	17.1	7.9	12.5	102.8	[illegible]	[illegible]	14.4	123.1	5.6	0.5	3.1		1875 Level
10	ITH-In the Hole Drill	●	-	96.9	10.1	13.0	11.5	98.7	4.1	13.7	7.4	120.0	0.0	1.5	0.75		1875 Level
11	ITH-In the Hole Drill	●	-	96.0	12.9	22.6	17.75	98.5	9.0	20.0	14.5	120.0	0.0	0.9	0.45		1875 Level
12	ITH-In the Hole Drill	◒	-	95.2	5.8	5.9	5.85	98.4	4.6	4.3	4.45	121.4	2.8	0.0	1.4		2000 Level
13	ITH-In the Hole Drill	○	-	105.2	10.3	12.5	11.4	108.8	7.8	9.6	8.7	129.3	3.7	0.8	2.25		2000 Level
14	ITH-In the Hole Drill	◒	-	99.1	9.0	7.7	8.4	100.7	6.8	5.5	6.2	121.6	1.9	1.2	1.5		3100 Level
15	ITH-In the [illegible] Drill	○	-	96.7	7.6	8.2	7.9	98.3	[illegible]	6.5	5.7	[illegible]	0.5	0.3	0.4		3100 Level
16	Diamond Driller	◒	13.75	101.8	17.7	1.4	9.5	107	12.3	6.7	[illegible]	[illegible]	28.0	26.9	27.45	Left arm on muff bent	1700 Level
17	Diamond Driller Helper	○	13.5	107.1	16.4	19.5	17.9	109.0	15.6	9.0	12.3	[illegible]	2.0	[illegible]	12.7		1700 Level
18	Air Slusher	○	13.25	112.1	7.6	5.3	6.4	116.2	9.1	6.2	7.7	148.0	[illegible]	22.0	22.5		3100 Level
19	Scooptram ST5	○	14.0	105.0	9.5	8.2	8.8	109.0	2.7	4.5	3.6	148.0	16.7	17.2	17.0		2400 Level
20	Scooptram JS500	○	-	99.9	11.1	11.3	11.2	116.4	21.9	14.5	18.2	148.0	21.6	12.1	16.9		3400 Level
21	Scooptram JS500	○	-	104.0	9.0	15.3	12.1	114.6	12.2	11.7	11.95	133.0	0.4	35.7	18.0		3100 Level
	Mean		13.54	106.06	12.11	11.97	12.02	109.94	10.41	11.42	10.92	135.55	10.42	12.90	11.41		
	Std. Dev.		0.27	8.02	4.08	6.33	4.30	8.22	6.45	5.35	4.19	11.02	9.50	11.70	9.06		

Note: ○ Satisfactory; ◒ Good; ● Very Good.

Attenuation tests of Mark IV, MSA; David Clark, model E-705; and Racal muffs in the ISO mode

No	Equipment	Comfort		L. Avg. (dBA)	Attenuation (dBA)			L. Max. (dBA)	Attenuation (dBA)			L. Peak (dBA)	Attenuation (dBA)			Comments	Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.		L.S	R.S.	B.S.		
									EAR MUFF - MARK IV								
1	2 Jack Leg Drills AL-60	-	13.5	118.7	12.4	8.4	10.4	124.0	3.2	8.1	10.8	148.0	9.3	9.4	9.15		3100 Level
2	Stoper Dr.-Rock Bltg.	○	-	110.8	15.3	5.4	10.3	117.5	13.1	6.4	9.7	148.0	16.0	13.0	14.50	Claims muffs not adjusted	3100 Level
3	2 Joy Stopers-Rock Bltg	○	13.0	114.0	4.9	0.5	2.7	119.7	5.8	3.2	5.0	147.8	12.8	13.3	13.1	Cushions bad shape, not worn	1800 Level
4	ITH-In the Hole Drill	○	13.75	97.7	6.1	8.4	7.2	101.5	7.3	9.7	8.5	148.0	28.0	28.0	28.0	Left arm on muff bent	3100 Level
5	ITH-In the Hole Drill	○	13.75	102.0	17.5	25.7	21.6	103.2	16.1	18.3	17.2	134.0	0.0	28.0	14.0		3100 Level
6	Diamond Driller	○	14.00	104.8	8.3	5.2	6.7	107.9	6.7	7.6	7.2	148.0	27.7	28.0	27.9	Cushions bad shape (bent arms)	1700 Level
7	Scooptram ST2	○	13.25	102.9	4.8	2.2	3.5	108.2	3.9	1.0	2.5	148.0	17.3	15.2	16.2	Cushions bad shape, not worn	2600 Level
	Mean		13.54	107.27	9.90	7.97	8.91	111.71	9.44	7.93	8.70	145.97	15.87	19.27	17.58		
	Std. Dev.		0.37	2.45	5.18	8.35	6.34	8.68	4.62	5.40	4.69	5.28	9.49	8.34	7.38		
									EAR MUFF - M.S.A. PELTOR (H7)								
1	Stoper Dr.-Rock Bltg.	●		115.4	28.7	25.2	26.9	120.5	27.1	24.8	26.0	138.5	13.8	15.6	14.7		1300 Level
									EAR MUFF - DAVID CLARK								
1	Diamond Driller-Help.	◒	14	105.2	23.1	9.0	16.0	108.9	23.6	9.2	16.4	148.0	28.0	23.7	25.9	Right arm on muff bent	1700 Level
									SAFETY MUFFS - RASCAL								
1	Scooptram ST500 (Rem Con)	○	14.25	100.4	6.3	1.0	1.3	114.4	11.3	11.7	11.5	148.6	17.3	17.3	17.3	No left adjustment	1300 Level

Note: ○ Satisfactory, ◒ Good; ● Very Good.

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Attenuation measurements of ear muffs at Strathcona Mine, 1984

1986

ATTENUATION MEASUREMENTS OF EAR MUFFS AT STRATHCONA MINE 1984

by

M.U. Savich* and J.K. Weglo**

ABSTRACT

Ear muffs are the main protection of the mining workforce for the attenuation of noise. The measurement of head size as against clamping force as well as the condition of the ear muffs are demonstrated as important variables in this attenuation of noise. The "NO NOISE" ear muff attenuation was about 13 dBA average with a standard deviation of 6 dBA at the Strathcona Mine. The Mark V ear muffs, replacing those in this study, based on clamping force measurements versus head size can be expected to produce attenuation >14 dBA.

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MESURE DE L'EFFICACITÉ DES CASQUES ANTIBRUIT À ATTÉNUER LE BRUIT À LA MINE STRATHCONA 1984

par

M.U. Savich* et J.K. Weglo**

RÉSUMÉ

Les casques antibruit sont la principale source de protection contre le bruit pour les travailleurs miniers. La mesure de la taille de la tête par rapport à la force de serrage ainsi que l'état des casques antibruit sont indiqués comme étant d'importantes variables de l'atténuation du bruit. Lors de l'étude à la mine Strathcona, le niveau d'atténuation du bruit "NO NOISE" des casques antibruit était en moyenne d'environ 13 dBA avec un écart type de 6 dBA. Cependant, d'après les mesures de la force de serrage par rapport à celles de la taille de la tête, les casques antibruit Mark V qui ont remplacé les casques utilisés dans cette étude pourraient assurer une atténuation du bruit de >14 dBA.

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INTRODUCTION

As part of the ongoing program of abating noise pollution at Falconbridge Mines measurements were taken to test the efficiency of ear muffs which were being used.

Tests were carried out at the Strathcona Mine where the following ear muffs were tested:

1) "NO NOISE", model NN3-F. the Hellberg Standard Volume Hearing Protector, hard hat attachment:
2) Mark IV, MSA, worn behind the head;
3) Peltor H7P3e, hard hat attachment;
4) Bilsom Viking Muff 2314, hard hat attachment; and
5) David Clark, Model E-705, Straightaway.

Most of the analyses were carried out on "NO NOISE" ear muffs, model NN3-F, because they were the ones used by 95% of the workers. The framework and method, as well as theoretical and practical considerations, are outlined in the main report, which should be read to compare Strathcona Mine results with other Falconbridge mines.

The latter three types have recently come into use in the mine. Only one test, for head size and clamping force, was performed on the David Clark muffs. On the other muffs both tests were performed, for head size/clamping force and attenuation, but the Peltor H7P3e and Bilsom 2314 muffs had very small populations (2 tests on the Peltor and only 1 test on the Bilsom muff).

Attenuation characteristics of the ear muffs, as supplied by the manufacturer using the ANSI protocol (reference) are given in Table 1. Noise reduction ratings (NRR) given in Table 1 are those which were supplied by the manufacturers. From these rating values it appears that all muffs provide relatively equal attenuation.

Table 1 - Attenuation characteristics of ear muffs acquired for testing (ANSI S3.19-1974).

No.	Ear Muff	Characteristic	Frequency Hz									NRR
			125	250	500	1000	2000	3150	4000	6300	8000	
1	"NO NOISE" Model NN3-F Hellberg	Mean	16.2	19.9	25.2	34.1	36.0	39.2	39.0	40.3	38.1	24
		Std. Dev.	2.5	1.8	2.0	1.7	2.2	3.1	2.0	4.0	4.1	
2	Mark IV, MSA	Mean	17.0	18.0	29.0	36.0	38.0	44.0	44.0	43.0	93.0	24
		Std. Dev.	2.6	2.6	3.1	3.2	4.1	7.2	4.6	4.7	5.7	
3	Peltor 47P3e	Mean	14.1	18.8	28.1	36.2	35.6	38.4	35.0	35.5	35.4	24
		Std. Dev.	2.1	2.0	3.0	2.1	2.2	2.3	2.1	2.1	2.4	
4	Viking Muff No. 2314, Bilsom	Mean	15.0	21.0	27.0	37.0	36.0	38.0	42.0	42.0	39.0	25
		Std. Dev.	1.8	2.0	2.5	2.8	1.5	2.3	3.0	3.7	3.6	
5	David Clark Model E-705 Straightaway	Mean	12.0	17.0	30.0	35.0	35.0	36.0	37.0	32.0	30.0	--
		Std. Dev.	2.5	3.0	4.6	5.6	4.5	4.3	4.2	4.1	2.9	

MEASUREMENTS AND RESULTS

At the Strathcona Mine the db 307 Metrosonics instrument was employed in virtually every test, and with its greater range it provided more exact attenuation measurements than other instruments.

The inability of the Brüel and Kjaer (B and K) dosimeters to provide exact attenuation figures when measured levels are greater than 115 dBA, or less than 80 dBA, may have been responsible for resultant attenuation differences.

The first technique at the Strathcona Mine employed one B & K dosimeter (microphone under muff), and one db 307 Metrosonics (microphone outside the muff). Both instruments were either OSHA (doubling at 5 dB), or ISO (doubling at 3 dB), monitoring noise levels simultaneously. This technique allowed the second technician to simultaneously monitor, with his hand-held instrument, his partner's dosimetry. This technique required a lot of 'man-handling'. Microphones and equipment had to be switched around at least four times per test: a complete scooptram test required 12 trips and many interruptions. To decrease inconvenience to the worker and to lessen the time required for dosimetry, two more pockets were added to the vest. Tests then took less time to complete because we to changed the microphones from side to side only once. The B & K was used for inside muff readings, and the Metrosonics for exterior readings.

Sound level tests with the hand-held instruments took longer to complete. Head size was measured with outside calipers, and clamping force with a manual balance.

HEAD SIZE AND CLAMPING FORCE

Head size and clamping force tests were performed on four ear muffs.

with varying populations (see Appendix A and summary results in Table 2).

In Table 2 it can be seen that results of 16 measurements on muffs No. 2, 3 and 4 are very similar to the results of 93 measurements on No. 1 "NO NOISE" ear muffs.

Ear muffs deteriorate rapidly with use. Mark IV MSA muffs have a strong clamping force, 1277 (gwt), but a very high standard deviation as well, 417 (gwt). Ninety per cent confidence in results is 1277 ± 234 (gwt), which is almost the same as factory-tested brand new muffs.

The normal frequency curve of population - 60 has two maxima (Figure 1). The first maximum is related to the curve's positive skewness. The flatter curve was plotted from clamping force tests on population - 93. Here too, we have head sizes of small bizygomatic diameter, 12.0 cm to 13.0 cm.

If we look at these two curves we see that their essences differ, and that a large number of measurements are needed for proper evaluation. The shape of the flatter curve is considered to be platykurtic. We measure peakiness by using the following formula:

$$\text{peakiness} = \frac{m_4}{S^4}$$

Moments are based on the sum of deviations from the mean of each of the individual sample details in a distribution. Our formula for peakiness is based on the fourth moment divided by the standard deviation to the fourth power.

$$m_4, \text{ fourth moment} = \frac{\Sigma(X - \bar{X})^4}{n} = \frac{\Sigma x^4}{n}$$

$$= 1.2 \text{ (platykurtic)}$$

The numerical value of this equation will be equal to 3 for a normal curve. For a leptokuric curve our answer will be greater than 3, while for a platykurtic curve it will be less than 3. What we can conclude is that, in practice, we must work with large numbers of measurements to obtain valid

Table 2 - Summary results of head size and clamping force tests

No.	Ear Muff	N*	Head Size (cm)		Clamping Force (gwt)		Comment
			Mean	Std. Dev.	Mean	Std. Dev.	
1	"NO NOISE" Model NN3-F Hellberg	93	13.92	0.77	1152.42	277.31	Used long time
2	Mark IV MSA	12	13.60	0.73	1277.00	417.00	Used long time
3	Peltor H7P3e	3	14.50	0.58	933.33	52.04	Almost new
4	David Clark	1	14.50	-	450.00	-	Almost new
	Σ(2 - 4)	16	13.89	0.76	1153.67	301.50	

Note: N* - Population

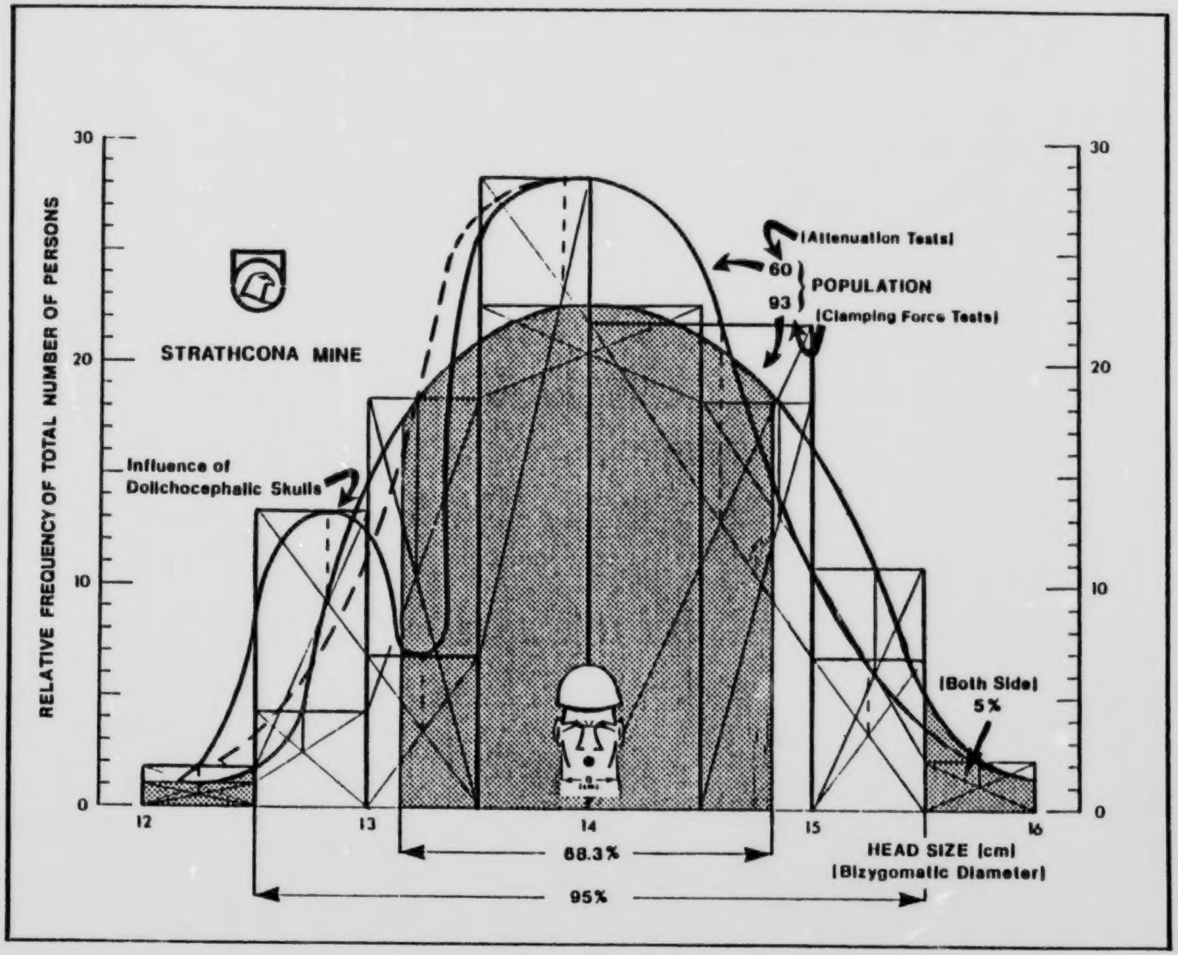

Fig. 1 - This bimodal frequency curve has two maxima: the first maximum is related to dollichocephalic skulls; and the second maxima is related to the curve's positive skewness (population 60). The flatter curve is considered to be platykurtic (population 93).

results. Moreover, we must work toward providing hearing protection for workers with head sizes ranging from 12 cm to 16 cm. In other words, we must secure a means whereby clamping force would remain almost constant over this range. The constructed platykurtic curve points us in that direction. In this country there are 250,000 cases with noise related disability, or 1% of the entire population. That is why we must not allow workers, whose head sizes are in the extremes, to suffer by losing their hearing from improper protection. An ear muff whose clamping force remains constant, or relatively constant, should be constructed to protect all workers equally.

The clamping force frequency curve has negative skewness (skewed to the left but only gently) (Figure 2). It is almost a normal curve. From this frequency curve it can be concluded that 85% of the work force has a clamping force greater than 1000 (gwt), which is a very good result for a large mine such as this one. By the same token, it is evident that deterioration of ear muffs is slow. This conclusion is backed by the bar graphs in Figure 3. From these graphs of clamping force versus head size, it can also be seen that ear muff deterioration is exascerbated by the population with head sizes of 13.5 cm to 14.0 cm. Also it can be seen that clamping force increases with head size.

Data from Appendix A was used to construct a standard deviation ellipse (see Figure 4). The ellipse in large part covers the field of head size versus ear muff clamping force, and we can therefore expect good but still incomplete attenuation.

LHD equipment is widely used at this mine. Frequency analyses were performed at the engine of a scooptram S-4A and at the operator's ear. The results were as follows:

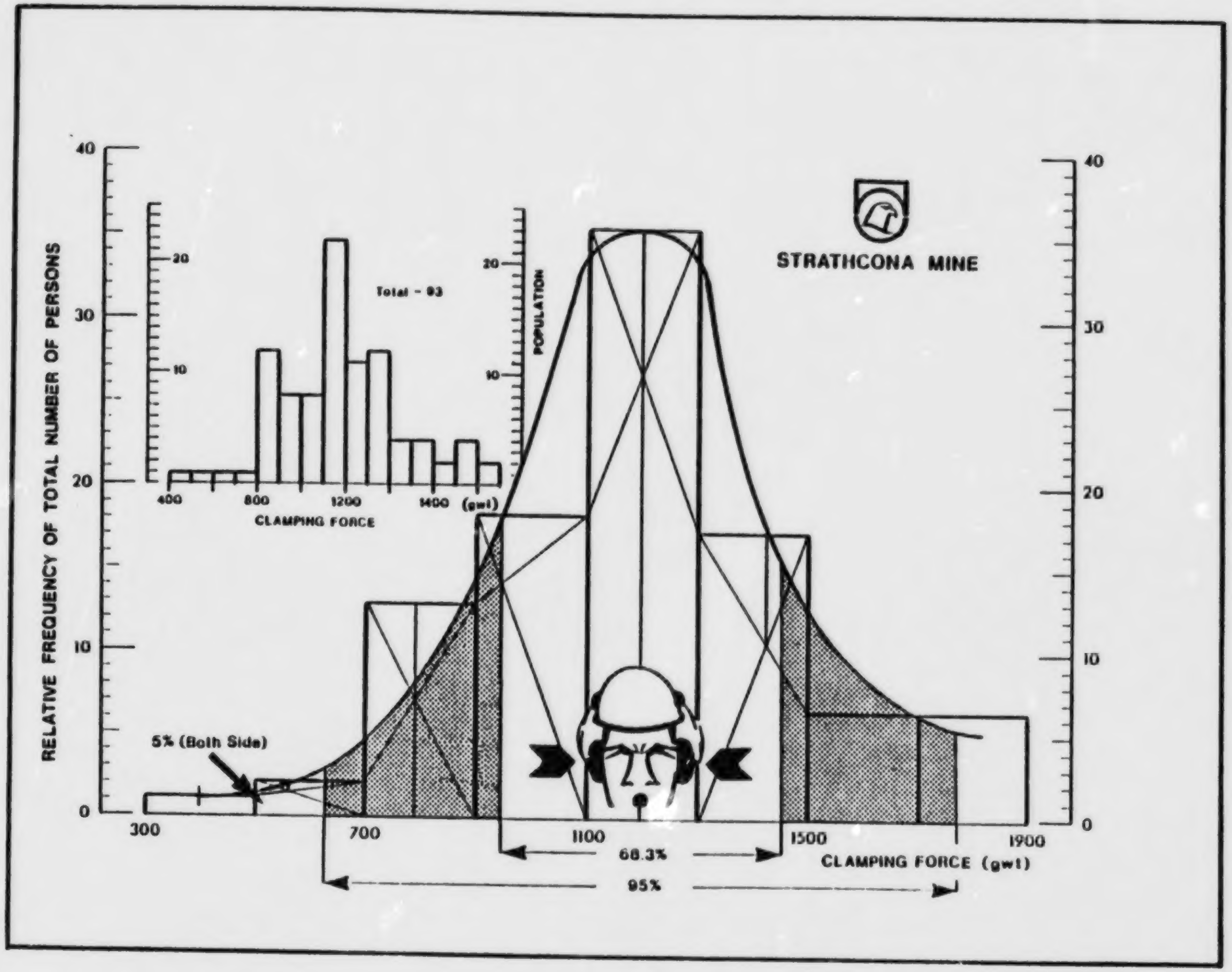

Fig. 2 - The clamping force frequency curve (note its skewness).

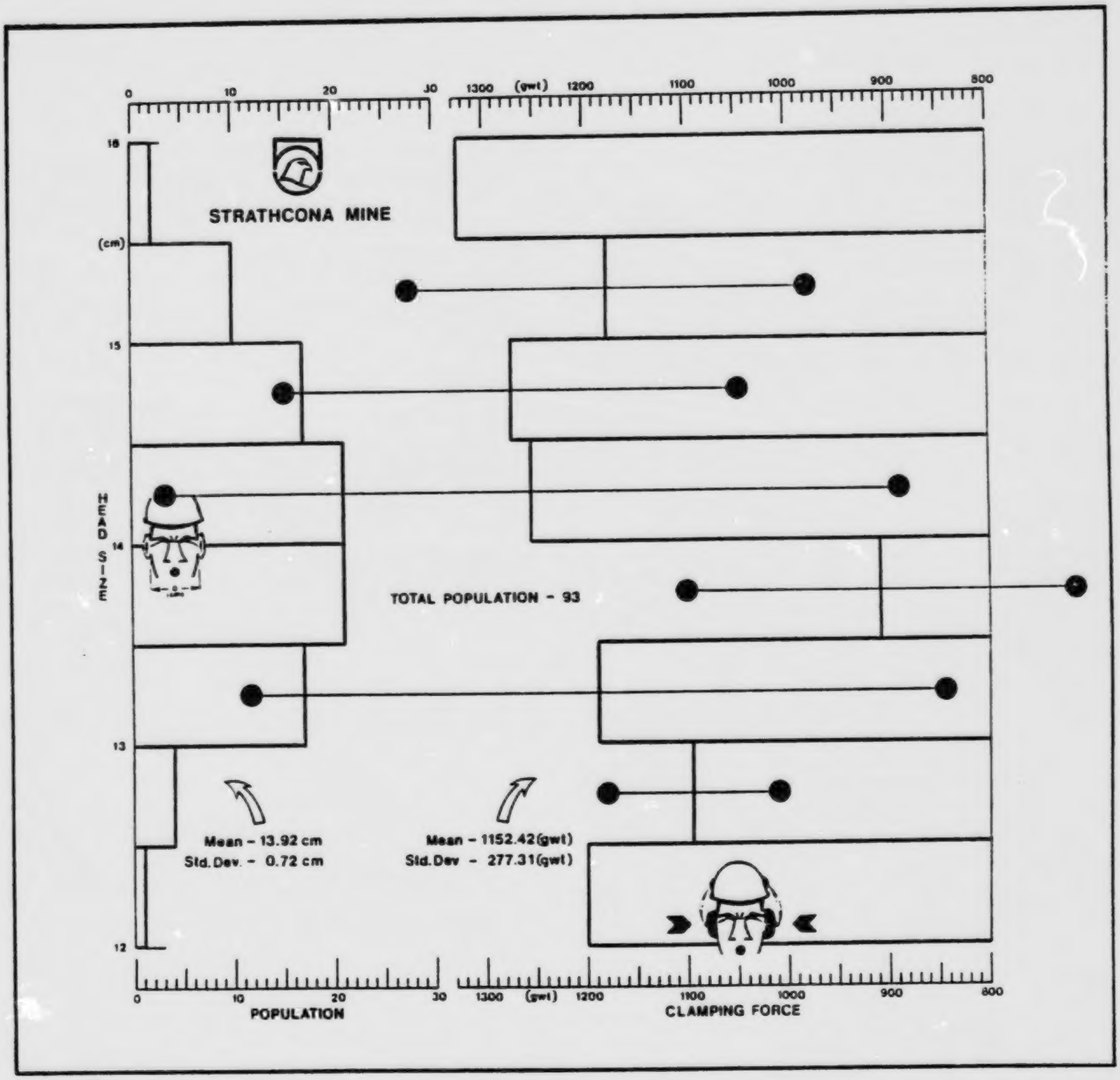

Fig. 3 - Relationships between head size and clamping force at the Strathcona Mine.

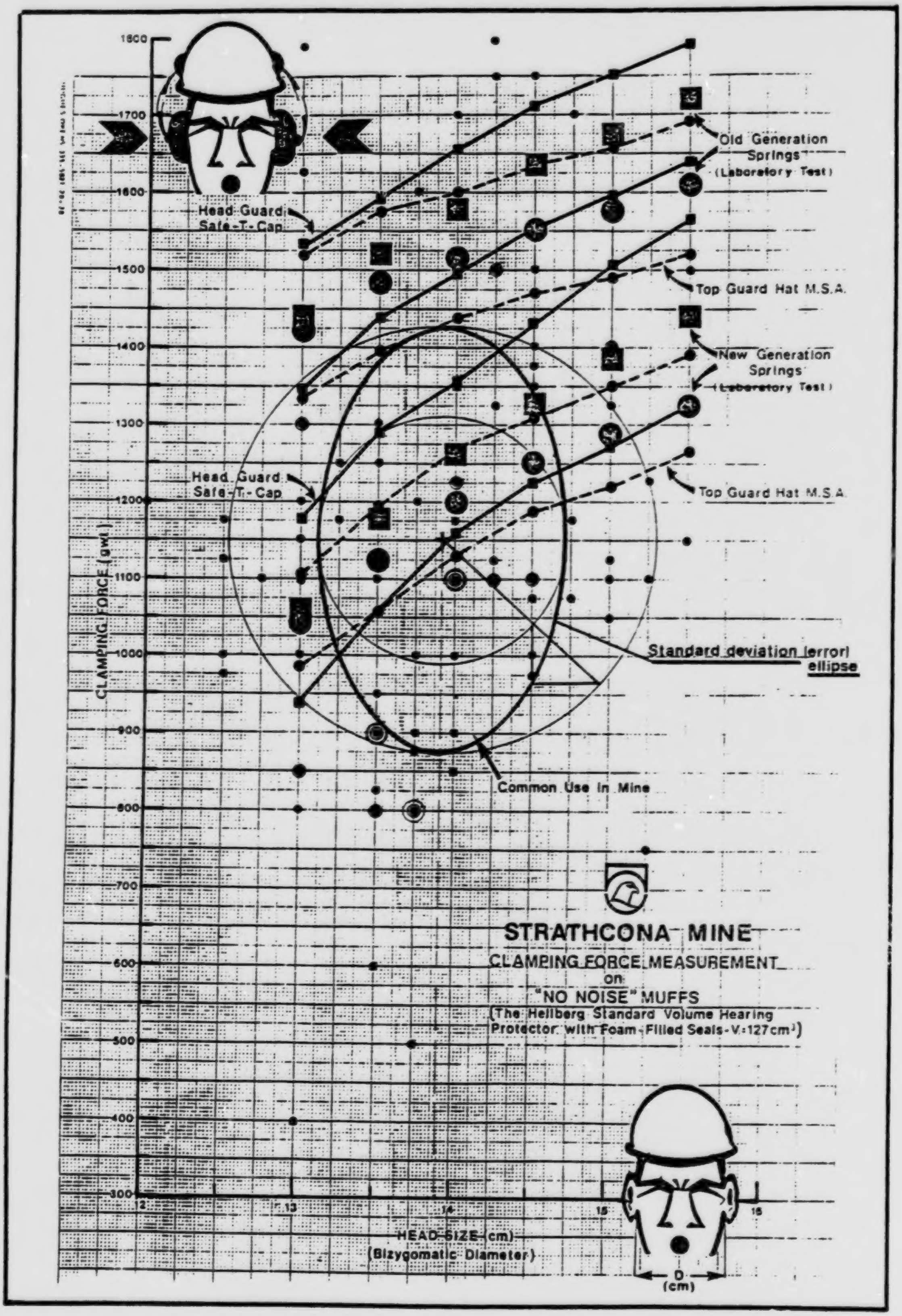

Fig. 4 - The standard deviation (error) ellipse of "NO NOISE" muffs at the Strathcona Mine.

Status	Frequency Hz - dB							dBA	dBC
	125	250	500	1k	2k	4k	8k		
At engine, average of both sides (1 m)	115.5	113.6	109.6	101.6	101.5	100.0	94.88	110.70	118.1
At operator's ear	107.75	103.25	99.5	94.5	92.5	88.75	82.25	101.25	112.2

The following equation can be used to estimate the sound level (dBA) at a worker's ear when he is wearing a personal hearing protector:

$$dBA = dBC - (NRR - 10)$$

where, dBC is the C-weighted sound level to which the operator is exposed: NRR is the Noise Reduction Rating of the protector: and 10 is a factor, based on "real world" conditions, used to "derate" the NRR. Based on this equation, the sound level at an operator's ear (in dBA) when he is working at a location where the sound level is 112.20 dBC, and using a personal hearing protector rated at NRR = 24, would be 98.2 dBA. Noise over ear muffs is 101.25 dBA. Theoretical attenuation would be only 3.05 dBA.

On the basis of six measurements, attenuation was 4.62 dBA, which is greater than theoretical attenuation by 1.57 dBA. Where low frequencies prevail ear muff efficiency is poor. Attenuation could be increased further by using ear plugs.

EAR MUFF CONDITION

Ear muffs were in good condition (Table 3). Here too, workers had a tendency to bend the springs of "NO NOISE" ear muffs in order to improve their comfort. In Figures 3 and 4 it can be seen that workers with head sizes from 13.5 cm to 14.0 cm did the most bending, though it is also true that they comprise the largest population.

This test, however, shows that more effort must be made to improve ear

Table 3 - Tests of ear muff conditions in mines and mills

No.	Ear Muff	N*	Ear Muff Conditions					
			Good		Fair		Poor	
			N_1	Percent	N_2	Percent	N_3	Percent
1	"NO NOISE" (NN3-F)	93	71	76.34	14	15.05	8	8.60
2	Mark IV, MSA	12	6	50.00	5	41.67	1	8.33
3	Peltor (H7P3e)	3	1	33.33	1	33.33	1	33.33
4	David Clark Model E-705 Straightaway	1	0	0.00	1	100.00	0	0.00
1-4	Σ	109	78	71.56	21	19.27	10	9.17

Note: * - Population ($N^* = N_1 + N_2 + N_3$)

muff conditions because 9% of them were deemed to be in poor shape.

ATTENUATION MEASUREMENTS

Attenuation measurements were performed on the following ear muffs:

1) "NO NOISE", model NN3-F, 39 measurements in OSHA mode (Appendix B), and 36 measurements in ISO mode (Appendix C);
2) Mark IV, MSA, 8 measurements in OSHA mode (Appendix D); and 10 measurements in ISO mode (Appendix E);
3) Peltor H7P3e, 2 measurements in OSHA model (Appendix D); and 2 measurements in ISO mode (Appendix E); and
4) Bilsom Viking Muff 2314, 1 measurement in OSHA mode (Appendix D), and 1 measurement in ISO mode (Appendix E).

Tests of "NO NOISE" ear muffs show that they have the following attenuation (Appendices B and C):

Mode	Characteristic	dBA	Confidence Limit	
			90%	95%
OSHA	Mean Std. Dev.	12.97 5.76	12.97±1.8 dBA	12.97±2.2 dBA
ISO	Mean Std. Dev.	13.10 6.38	13.10±2.0 dBA	13.10±4.0 dBA

At the Strathcona Mine almost 98% of the miners wear ear plugs, especially the yellow foam plugs made by E.A.R. which have a NRR of 29 dBA. Complaints about ear muffs are frequent: it hurts behind the ears when glasses are worn; they are uncomfortable in hot areas; when the head moves the muffs also move and must constantly be readjusted, etc. Because of these complaints many workers choose to use only ear plugs. At the Strathcona Mine, mainly "NO NOISE" muffs are used. 78% of the test group wore them. The best attenuation achieved with these was 24.6 dBA. Many of the workers wear both ear plugs and muffs, though a few insist they cannot tolerate ear plugs*.

COMFORT OF EAR MUFFS

Good attenuations were demonstrated by Peltor ear muffs, but only on two occasions (Appendices D and E). At the time, they were fairly new, and so it would be unwise to draw conclusions from these two measurements alone.

Overall comfort was not the best. This is to be expected since the error ellipse points to the existence of limited efficiency (Figure 4). Comfort grading results are given in Table 4. If we compare these results with those in Figure 4, we can determine the precise relationship which exists between clamping force and comfort. The integrated ellipse gives the following results:

1) 56.8% of the ellipse's surface area covers the field of clamping force versus head size.
2) 43.2% of the ellipse's surface area does not cover the field of clamping force versus head size.

From Table 4, 54.2% of the workers deemed comfort satisfactory. Attenuation and comfort are in an inverse relationship.

Using Appendices B and C, measurement results were calculated for L_{max} and L_{peak} levels (Table 5). The aim was to see how big the "peaks" are, which according to some authorities, stimulate loss of hearing (2). Measurements were made with an integrating sound level meter, B & K, type 2225. Instrument control was performed to find means of standard deviations for L_{max} and L_{peak}. Result confidences are as follows:

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*This discovery was investigated by the Occup. Health Nurse, Bev Harris, and remedied.

Table 4 - Comfort of ear muffs in mines and mills

No.	Ear Muff	N*	○ -Satisfactory		◒ -Good		● -Very Good	
			N_1	Percent	N_2	Percent	N_3	Percent
1	"NO NOISE" (NN3-F)	46	29	63.0	17	37.0	0	0.0
2	Mark IV, MSA	10	3	30.0	7	70.0	0	0.0
3	Peltor (H7P3e)	2	0	0.0	1	50.0	1	50.0
4	Bilsom No. 2314	1	0	0.0	1	100.00	0	0.0
1-4	Σ	59	32	54.24	26	44.07	1	1.69

Note: * Population ($N^* = N_1 + N_2 + N_3 + N_4$)

Confidence Limit			
90%		95%	
L_{max}	L_{peak}	L_{max}	L_{peak}
4.51±1.35 dBA	5.0±1.66 dBA	4.51±1.66 dBA	5.00±1.16 dBA

From these results we can see that the measurements were very precise (±1.5 dBA). This is better than predicted for the Type 2 Sound Level Meter ±2 dBA (overall tolerance) (3).

CONCLUSIONS

Measurements have shown that the attenuation of "NO NOISE" muffs at the Strathcona Mine is about 13 dBA. For each type of machine the dBA or dBC or peak frequency range should be obtained so that the theoretical efficiency of ear muffs can be ascertained. The overall condition of ear muffs is fairly good, but it should be noted that 8.6% of them were found to be in poor condition. To make an improvements, cushions should be replaced more often and the bending of spring-loaded arms should be controlled. The employer should ensure that workers are trained correctly in properly fitting ear muffs. Head shapes and sizes had a marked effect on attenuation, as did job function (e.g., how much head turning is required at specific jobs). Physical obstruction (e.g., eye glasses) weakened attenuation. Because scooptrams are widely used in the mine, it was possible to demonstrate theoretical attenuation of 3 dBA. Noise under ear muffs come out to about 98 dBA. If we wished to attenuate the high levels of noise to below 90 dBA using ear plugs in conjunction with muffs would not be sufficient. Ear muffs alone are not a complete solution to the attenuation of noise.

Ear muff control should be continued, by measuring head size and clamping force with the apparatus suggested in the main report.

Table 5 - Peak levels in mining, milling and smelting operations at the Strathcona and Falconbridge Mines.

Falconbridge - Strathcona

Instrument: Bruel and Kjaer Integrating Sound Level Meter Type 2225.

No.	Sound Source	dBA		Δ	N
		L_{max}	L_{peak}		
		Mean Std. Dev.	Mean Std. Dev.		
1	Jack Leg Drill	118.65 3.36	134.85 5.68	16.3	11
2	Stoper Drill - Rock Bolter	118.51 5.92	135.0 7.0	16.5	22
3	Jumbo Drill - two booms	116.96 5.91	122.14 5.91	15.19	8
4	Long Hole Drill	119.19 1.98	135.08 2.59	15.39	4
5	Long Tom Drill - two booms	120.27 2.99	137.17 4.63	16.9	23
6	ITH In the Hole Drill	98.27 5.12	116.25 5.66	17.98	7
7	Diamond Drill	104.02 4.76	120.81 9.93	16.79	7
8	Mucking Machine	106.58 3.60	121.53 3.53	14.95	4
9	Bolting Machine	-	-	-	-
10	Air Plugger (Brk. Cement)	-	-	-	-
11	Slusher	97.50 4.99	111.35 4.45	13.85	4
12	Scooptram	106.55 14.57	123.33 11.80	16.78	12
13	Conveyor Man	94.83 6.40	112.15 8.35	17.32	3
14	Chute Puller	114.80 9.19	133.15 3.32	18.35	2
15	Vent. Fan - 38" 60 HP	-	-	-	-
16	Primary Crusher - U/G Jaw Crush.	102.34 6.93	121.56 8.24	19.22	8
17	Secondary Crusher	91.77 1.33	106.27 1.62	14.5	3
18	Tertiary Crusher	95.43 0.21	108.35 0.64	12.9	2
19	Ball Mill	93.20 2.02	107.57 1.16	14.37	3
20	Flotation Op. Area	85.9	99.3	13.4	1
21	Compressor Room	89.7	103.0	13.3	1
22	Power House	94.5	107.5	13.0	1
23	Electrostatic Precipitator	93.65 0.35	109.20 3.82	15.55	2
24	Converter Puncher	99.13 1.10	114.27 1.79	15.14	3
25	Converter Skimmer - Fluxing	89.47 4.76	103.83 4.91	14.36	3

	$Mean_{SD}$ Std.Dev.	$Mean_{SD}$ Std.Dev.	
○ 19	4.51 3.45	5.00 3.04	19 ○

ACKNOWLEDGEMENTS

The authors wish to acknowledge the help and cooperation of E. Isaacs, and P. Savalas of M.A.P.A.O. as well as D.J. Cornett, Mine Superintendent, D. McPhee and R. Desjardins, Technicians, and L. Montpellier, Safety Department, and Dr. A.G. Cecutti, Medical Director of Falconbridge Ltd.

Acknowledgement are also extended to J. Vergunst, Working Environment Engineer, Ontario Ministry of Labour, Sudbury, and R. Pleasance, Branch Manager, Levitt Safety (Metrosonics Inc.), Sudbury for the loan of the instruments.

Thanks also go to G. Knight, Research Scientist, Elliot Lake Laboratory for reviewing the manuscript and making numerous helpful suggestions.

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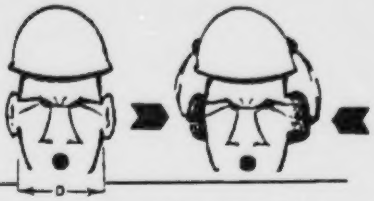
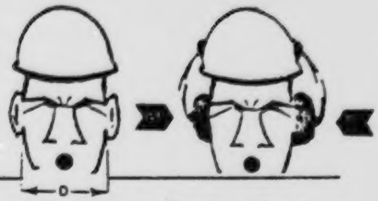
Head size and clamping force data of "NO NOISE" Model NN3-F ear muffs



No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Driller	1	13.75	800
2	Driller	1	13.00	1300
3	Driller	1	14.50	1350
4	Driller	1	13.25	1100
5	Driller	1	15.50	1150
6	Driller	1	12.50	975
7	Driller	1	13.75	900
8	Driller	2	13.75	800
9	Driller	1	14.00	900
10	Driller	2	13.00	850
11	Driller	2	14.25	1750
12	Driller	3	13.75	500
13	Driller	1	13.75	875
14	Driller	2	13.50	500
15	Driller	2	15.25	750
16	Driller	1	14.50	1300
17	Driller	2	14.25	1100
18	Driller	1	14.50	1075
19	Long Hole Driller	1	15.50	1500
20	Long Hole Driller	1	13.00	1300
21	Long Hole Driller	1	13.00	1450
22	Long Hole Driller	3	13.50	1250
23	Long Hole Driller	1	12.50	1125
24	Long Hole Driller	1	12.75	1100
25	Long Hole Driller	1	13.75	1000
26	Long Hole Driller	1	13.50	900
27	Jumbo Driller	1	14.50	1100
28	Jumbo Driller	1	13.75	1200
29	Jumbo Driller	1	13.50	1000
30	Jumbo Driller	2	13.00	850
31	Diamond Driller	1	14.50	975
32	Driller Scooptram	1	14.50	1400
33	Driller Scooptram	3	13.75	800
34	Driller Scooptram	3	15.00	1125
35	Driller Scooptram	1	14.50	1300
36	Driller Scooptram	1	14.50	1000
37	Driller Scooptram	2	13.00	1000
38	Driller Scooptram	1	12.50	1175
39	Driller Scooptram	1	13.50	900
40	Stope Boss	3	13.00	400
41	Stope Boss	1	14.25	1100
42	Stope Boss	1	14.50	1350
43	Training	1	14.75	1075
44	Timberman	2	13.50	600
45	Timberman	1	14.00	1100
46	Pipefitter	1	14.00	1250
47	Pipefitter Helper	1	13.50	325
48	Trackman	1	13.00	1625

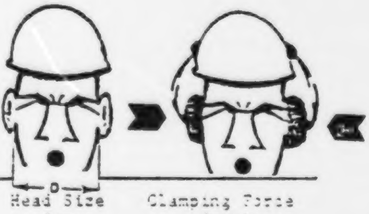
Cont. overleaf



No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
49	Scooptram	1	13.00	1150
50	Scooptram	1	13.00	1200
51	Motorman	1	13.00	1100
52	Motorman	1	14.50	1225
53	Nipper	1	14.00	1175
54	Nipper	1	13.50	1100
55	Ore Pass Tender	1	14.75	1175
56	Ramp Haulage	1	13.00	1300
57	Blaster Helper	1	15.25	1225
58	Diesel Mechanic	3	13.50	800
59	Diesel Mechanic	3	15.00	1050
60	Diesel Mechanic	2	14.00	1700
61	Diesel Mechanic	1	14.00	1225
62	Diesel Mechanic	1	13.00	1625
63	Diesel Mechanic	1	14.00	1225
64	Mechanic	2	13.50	900
65	Mech. Foreman	1	13.25	1300
66	Electrician	1	14.25	1325
67	Electrician	1	13.00	1100
68	Construction	1	14.00	1100
69	Construction	1	15.00	1400
70	Construction	1	14.50	1375
71	Construction	1	14.00	1200
72	Bonus man	1	14.50	1750
73	Bonus man	1	14.25	1300
74	Level Cleaner	1	14.00	1350
75	Level Cleaner	1	14.00	1000
76	Level Cleaner	1	14.50	1175
77	Vent. Technician	1	15.00	1400
78	Vent. Technician	1	15.00	1325
79	Vent. Technician	1	13.50	950
80	Shaft Inspector	2	14.75	1700
81	Shaft Inspector	3	14.00	850
82	Safety Supervisor	1	14.25	1125
83	Safety Advisor	1	13.50	1300
84	Shift Boss	2	13.50	900
85	Shift Boss	1	14.25	1000
86	Surveyor	1	14.00	1100
87	Surveyor	1	15.00	1300
88	Surveyor	1	13.25	1175
89	Geologist	1	13.25	1250
90	Ground Control	1	14.25	1300
91	Mine Captain	1	12.00	1200
92	Mine Captain	1	14.50	1100
93	Mine Captain	1	13.00	800
	Mean:		13.92	1152.42
	Std. Dev.:		0.77	277.31

Note: 1 - Good; 2 - Fair; 3 - Poor.

Head size and clamping force data of three different muffs: MSA Mark IV; Peltor H7P3e; and David Clark, Model E-705



MARK IV MUFFS

No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Driller	1	14.00	1200
2	Long Hole Driller	1	13.50	1225
3	Long Hole Driller	2	13.00	1350
4	Driller Scooptram	2	14.25	950
5	Stope Boss	1	14.25	1200
6	Nipper	3	14.75	1900
7	Diesel Mechanic	2	14.00	900
8	Mechanic	2	12.50	1100
9	Level Cleaner	2	14.00	1025
10	Bonus Man	1	13.00	900
11	Surveyor	1	12.50	925
12	Safety Advisor	1	13.50	1950
	Mean:		13.60	1277.00
	Std. Dev.:		0.73	417.03

PELTOR MUFFS (H7)

No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Stope Boss	1	14.50	875
2	Level Cleaner	3	14.50	975
3	Ventilation Man	2	13.50	950
	Mean:		14.17	933.33
	Std. Dev.:		0.58	52.04

DAVID CLARKE MUFFS

No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Diamond Drill Foreman	2	14.50	450
Σ	Mean:		13.89	1153.67
	Std. Dev.		0.76	301.50

Note: 1 - Good; 2 - Fair; 3 - Poor.

Attenuation tests of "NO NOISE", Model NN3-F, the Hellberg standard volume hearing protector - OSHA mode

No.	Equipment	Comfort		L_{OSHA} (dBA)	Attenuation (dBA)			L_{OSHA} (dBA)		L450 (dBA)				Comments	Location
					L.S.	R.S.	B.S.	Max	Peak	L_{eq} (60s)	Slow	Fast	Peak		
1	Stoper Dr. Jack Bltg.	○	14.0	110.8	18.4	19.4	18.9	118.6	136.0	115.4	117.0	117.4	132.5		2600 Level
2	Stoper Dr. Rock Bltg. (Y. Rivard)	◒	13.5	106.9	23.2	17.4	20.3	117.55	·141.7	118.2	117.8	119.3	132.2	Outside meas. too low	2500 Level
3	Stoper Dr. Rock Bltg. (J. Regis)	○	15.0	–	–	–	–	-	–	118.2	117.8	119.3	132.2	Mallon. Metros dB-307	2500 Level
4	Stoper Dr. Rock Bltg. (H. Lapointe)	○	13.75	111.1	15.0	8.5	11.8	119.2	137.2	116.4	119.4	119.4	131.3	L450 - common meas.	2500 Level
5	Stoper Dr. Rock Bltg. (Y. Briton)	○	13.75	114.0	10.2	9.6	9.9	118.2	135.7	116.4	119.4	119.4	131.3		2500 Level
6	Stoper Dr. Rock Bltg. (B. Ekenhour)	◒	12.50	116.6	12.8	20.3	16.6	125.35	143.0	114.9	120.4	121.2	136.4		1800 Level
7	Stoper Dr. Rock Bltg. (A. Joulet)	◒	13.75	115.8	12.2	12.7	15.3	119.5	137.1	118.1	118.8	120.0	135.0		1800 Level
8	Stoper Dr. Rock Bltg. (R. Seguin)	○	14.5	115.0	19.8		-	113.8	135.0	117.7	117.9	116.1	134.7	Wore plugs RE dB-307 affected by humidity	2300 Level
9	Stoper Dr. Rock Bltg. (Y. Viens)	○	12.25	115.4	15.0	15.0	15.0	119.0	138.7	118.8	118.5	118.2	131.8		2700 Level
10	Stoper Dr. Rock Bltg. (R. Gervais)	○	12.5	109.0	28.8	14.8	21.8	116.0	–	118.2	118.7	118.5	133.8		2700 Level
11	Jumbo Dr. (Elec. Hydr.) (D. Bertrand)	◒	14.5	100.6	·19.5	·21.7	20.6	107.1	121.6	102.4	103.4	102.7	113.5	Borrowed muffs	2600 Level
12	Jumbo Dr. (Elec. Hydr.) (M. Pelletier)	◒	13.0	95.7	·17.8	4.2	·11.0	102.6	120.0	101.2	96.9	95.6	113.9	Operator struggling primarily 1 boom op.	1800 Level
13	Long Hole Drill (L. Rivest)	◒	14.5	119.1	10.5	14.6	12.6	126.9	>145.3	116.6	117.6	117.4	133.5		2700 Level
14	Long Hole Drill (G. Bellanger)	○	13.5	117.5	4.9	3.3	2.6	119.5	138.3	118.6	117.6	118.0	132.7	Pads flat - supplied new cushions	2200 Level
15	Long Hole Drill (S. Cthier)	○	14.25	116.9	10.6	8.2	9.4	119.6	142.2	–	-	-	..		2200 Level
16	Long Tom Drill (2 boom)(D. Lamb)	◒	13.0	118.6	19.7	18.9	19.3	–	–	111.4	114.9	115.1	129.6	Plugs & muffs worn	2700 Level
17	Long Tom Dr. (2 boom)(D. Besserer)	◒	14.5	117.6	19.8	13.0	16.4	125.4	136.8	118.0	117.2	117.5	132.7	Plugs & muffs worn	2700 Level
18	Long Tom Dr. (2 boom)(Y. Rivard)	◒	13.5	119.2	17.9	23.0	20.5	124.85	143.9	121.2	119.2	120.1	133.5		2500 Level
19	Long Tom Dr. (2 boom)(J.P. Regis)	○	15.0	118.2	17.1	17.2	17.2	122.8	144.3	121.3	121.6	121.8	136.3		2500 Level
20	Long Tom Dr. (2 boom)(L. MacDonald)	–	13.26	111.0	18.3	15.2	16.8	117.75	137.5	114.5	116.1	115.6	129.6	Only 1 boom operating	2425 Level
21	Long Tom Dr. (2 boom)(R. Lapensee)	○	13.5	·115.0	·2.5	4.7	·3.6	–	-	121.6	120.6	121.9	135.2		2300 Level

Cont. overleaf

No.	Equipment	Comfort		L_{OSHA} (dBA)	Attenuation (dBA)			L_{OSHA} (dBA)		LISO (dBA)				Comments	Location
					L.S.	R.S	I.S.	Mix	Peak	Leq (60s)	Slow	Fast	Peak		
22	Long Tom Dr. (2 boom)(R. Lafleur)	○	14.5	114.9	2.2	17.5	9.9	118.35	137.6	-	-	-	-	Drilled 2 holes only	2600 Level
23	Long Tom Dr. (2 boom)(W. Beaudry)	○	14.0	118.2	17.9	17.9	17.9	121.0	141.4	116.8	116.4	116.4	131.7		2600 Level
24	ITH In the Hole Drill (P. Audette)	○	14.5	98.9	>18.9	>18.9	>18.9	102.2	121.6	101.0	99.7	99.6	115.7	Plugs and muffs worn	1200 Level
25	ITH In the Hole Drill (R. Lamothe)	○	12.75	92.7	>13.7	>11.6	>12.7	96.7	<120.0	93.2	93.5	93.6	111.0	Eqipped with muff but only plugs worn	2900 Level
26	Diamond Drill (L. Laporte)	◒	15.0	100.8	11.9	>20.4	>17.2	102.7	<121.5	97.6	98.4	97.5	109.7	Good muffler on motor and pump	2600 Level
27	Diamond Drill (G. Gratton)	◒	12.5	105.5	>23.5	14.0	18.8	110.7	128.4	108.7	107.6	107.6	121.0		2600 Level
28	Diamond Drill (R. Rhyno)	◒	15.0	107.0	>27.1	>26.9	>27.0	110.3	121.5	105.7	106.9	106.6	118.7	V. noisy ventilation	2600 Level
29	Conveyor Man (L. Hazgai)	○	14.75	96.2	+1.2	+3.1	+2.2	100.1	<120.0	96.5	96.3	96.4	109.7	R-Conveyor, much vib.	2900 Level
30	Chute Puller (L. Lapointe)	○	-	99.6	8.5	7.3	7.9	118.3	137.1	107.2	108.5	108.3	130.8	2 diff. chutes used	2900 Level
31	Scooptram ST-5 (F. Belanger)	○	14.5	104.0	7.9	4.7	6.3	-	-	-	-	-	-		2700 Level
32	Scooptram (R. Lamothe)	○	12.75	101.5	4.3	2.6	3.5	-	-	102.3	102.8	103.0	120.5	Loading Fuel	2900 Level
33	Scooptram (A. Leblanc)	○	12.5	102.3	5.3	3.3	4.3	110.15	151.6	-	-	-	-		2500 Level
34	Scooptram ST 2 (L. Morin)	○	13.5	97.4	13.6	>15.5	>14.6	106.15	<139.9	92.7	92.5	93.7	111.5	SLM readings diff. to obtain - lower than ac.	2300 Level
35	Scooptram ST 5 (G. Plamondon)	◒	13.0	97.5	16.5	>18.5	>17.5	117.4	<143.9	95.5	99.2	98.0	115.8	Remote loading - wears plugs - borrowed muffs	2300 Level
36	Scooptram Elec. (C. Claudette)	○	13.5	91.2	>6.8	>11.8	>9.3	102.3	<116.1	85.5	88.0	88.3	110.2	Wears plugs only	1800 Level
37	U/G Jaw Crusher (M. Morin)	○	14.0	97.8	+1.7	0.6	10.6	107.65	130.7	97.7	96.5	97.0	114.7	Wears plugs only, muff useless when head turns	2700 Level
38	U/G Jaw Crusher (E Labranche)	◒	13.5	99.3	4.3	3.6	4.0	112.9	134.0	98.4	96.6	95.0	113.4	Plugs and muffs worn	3000 Level
39	U/G Jaw Crusher (R. Denommé)	○	14.25	98.3	9.6	7.9	8.8	108.15	130.4	99.1	99.4	98.9	118.6		3000 Level
	Mean		13.75	107.38	13.40	11.83	12.97	114.08	135.36	109.00	109.50	103.55	124.99		
	Std. Dev.		0.82	8.93	6.47	6.77	5.76	8.11	6.59	10.17	10.59	10.71	9.63		

Note: ○ Satisfactory; ◒ Good; ● Very Good

Undetermined number (<No.; >No. and (No.) are not in Mean value.

Attenuation tests of "NO NOISE", Model NN3-F
the Hellberg standard volume hearing protector - ISO mode

No	Equipment	Comfort		L_{ISO} (dBA)	Attenuation (dBA)			L_{ISO} (dBA)		L_{OSHA} (85) (dBA)	Comments	Location
					L.S.	R.S.	B.S.	Max	Peak			
1	Jack Leg Drill (A. Goulet)	◒	13.75	115.3	10.0	16.1	13.1	122.0	140.35	114.5		1800 Level
2	Jack Leg Drill (B. Fiacehon)	◒	12.50	115.6	8.7	16.9	12.8	119.5	142.7	111.8		1800 Level
3	Stoper Dr. Rock Bltg. (Y. Viens)	○	12.25	117.1	15.0	14.9	14.95	120.6	140.75	-		2700 Level
4	Stoper Dr. Rock Bltg. (Y. Britton)	○	13.75	115.1	12.8	12.3	12.55	119.2	136.75	112.9		2700 Level
5	Stoper Dr. Rock Bltg. (H. Lapointe)	○	11.75	116.9	18.2	19.0	18.6	121.2	140.1			2700 Level
6	Stoper Dr. Rock Bltg. (R. Gervais)	○	12.50	115.7	-	16.4	-	-	118.7	-		2300 Level
7	Stoper Dr. Rock Bltg. (J. Regis)	○	15.01	116.5	10.5	21.23	15.87	121.0	144.6	104.5		2500 Level
8	Stoper Dr. Rock Bltg. (Y. Rivard)	◒	13.50	111.85	18.5	26.0	22.25	120.0	119.5	-		2500 Level
9	Stoper Dr. Rock Bltg.	○	14.00	116.6	29.13	18.33	23.73	119.7	136.8	-		2600 Level
10	Long Hole Dr. (C. Ethier)	○	14.25	118.25	17.2	8.4	12.8	119.5	135.6	115.0		2225 Level
11	Long Hole Dr. (G. Belanger)	○	13.50	119.75	19.6	20.9	20.25	121.85	138.5	115.0	Pads flat - supplied new cushions	2225 Level
12	Long Hole Dr.	◒	14.50	118.25	6.6	18.6	12.6	124.35	144.25	116.4		2700 Level
13	Jumbo Dr. (Elec. Hydr.) (M. Pelletier)	◒	13.25	94.2	11.2	7.2	9.2	105.4	122.05	99.6	Alimac	1825 Level
14	Jumbo Dr. (Elec. Hydr.)	◒	14.50	106.1	24.5	24.8	24.6	108.0	130.1	-	Atlas Copco	2600 Level
15	Long Tom Drill (M. Boudrie)	○	14.00	119.25	8.6	23.7	16.15	121.6	150.05	113.75		2600 Level
16	Long Tom Drill (R. Lafleur)	○	14.50	119.5	19.3	22.7	21.00	121.5	140.05	111.54		2600 Level
17	Long Tom Drill (L. McDonald)	○	13.25	114.2	16.8	17.2	17.00	118.5	137.35	95.49	Only one boom operating	2325 Level
18	Long Tom Drill (J.P. Regis)	○	15.0	119.25	14.3	17.2	15.75	121.3	141.1	117.0		2500 Level
19	Long Tom Drill (Y. Rivard)	◒	13.50	119.1	15.1	27.0	21.05	126.0	141.9	116.1		2500 Level
20	Long Tom Drill (D. Brassett)	◒	14.50	118.75	16.1	12.8	14.45	119.6	145.5		Wears plugs and muffs	2700 Level

Cont. overleaf

No.	Equipment	Comfort		L_{ISO} (dBA)	Attenuation (dBA)			L_{ISO} (dBA)		L_{OSHA} (85) (dBA)	Comments	Location
					L.S.	R.S.	B.S.	Max	Peak			
21	Long Tom Drill (D. Lamb)	◒	13.00	111.9	19.7	3.9	11.8	-	-	-	Wears plugs and muffs	2700 Level
22	Long Hole Drill ITH (G. Fortier)	○	12.75	92.15	·11.3	·13.5	>12.35	94.0	·120.0	93.23	Very quiet drill	1225 Level
23	Long Hole Drill ITH (P. Audette)	○	14.50	99.8	·19.0	>20.6	·19.8	104.0	123.2	101.55	V. quiet drill - plugs & muffs worn	1725 Level
24	Diamond Drill (B. Rhyno)	○	15.00	104.15	·26.2	20.0	23.1	108.7	122.05	106.5	V. noisy ventilation in this area	2625 Level
25	Diamond Drill (G. Gratton)	◒	12.5	107.75	26.8	14.27	29.5	-	-	107.4		2625 Level
26	Diamond Drill (L. Laport)	◒	15.0	101.8	·21.3	15.7	·18.5	108.1	140.35	97.5		2526 Level
27	Shute Puller (L. Lapointe)	○	-	103.35	9.4	6.9	8.15	121.3	135.5	104.4	2 different chutes involved in test	2900 Level
28	Conveyor Man (C. Mazgai)	○	14.75	96.0	0.37	3.1	1.7	100.3	121.45	95.5	B conveyor - much vibration here	2900 Level
29	Scooptram ST-5 (C. Claudette)	○	13.5	97.15	·11.7	7.3	9.5	101.95	127.6	-	Wears plugs only	1825 Level
30	Scooptram ST-5 (G. Plamondon)	◒	13.0	102.5	5.2	9.0	7.1	115.8	135.25	116.75	Remote loading - wears plugs - borrowed muffs.	2300 Level
31	Scooptram ST-5 (L. Morin)	○	13.5	99.0	17.0	15.0	16.0	142.45	128.9	-		2325 Level
32	Scooptram ST-5 (A. Leblanc)	○	12.5	101.4	3.5	2.0	2.75	114.4	140.2	-		2500 Level
33	Scooptram ST-5 (R. Lamothe)	○	12.75	103.2	4.9	1.5	3.2	117.7	144.25	101.5		2900 Level
34	U/G Crusher (R. Bourrine)	○	14.25	99.95	1.6	11.4	7.5	108.1	130.55	78.1		1000 Level
35	U/G Jaw Crusher (L. Labrouthe)	○	13.5	102.05	4.5	5.5	5.0	113.8	132.5	95.3	Wears plugs and muffs	1000 Level
36	U/G Jaw Crusher (Morrice)	○	14.0	101.8	3.3	1.0	2.15	106.0	130.75	-		2700 Level
	Mean		13.72	109.11	12.62	11.68	13.10	115.82	134.25	105.07		
	Std. Dev.		0.84	8.92	7.17	7.19	6.38	9.78	7.35	8.11		

Note: ○ Satisfactory; ◒ Good; ● Very Good

Undetermined numbers (No.) are not in Mean value.

Attenuation tests of different models of ear muffs - OSHA mode

No	Equipment	Comfort		L_{OSHA} (dBA)	Attenuation (dBA) L.S.	Attenuation (dBA) R.S.	Attenuation (dBA) B.S.	L_{OSHA} (dBA) Max	L_{OSHA} (dBA) Peak	L_{ISO} (dBA) L_{eq} (60s)	L_{ISO} (dBA) Slow	L_{ISO} (dBA) Fast	L_{ISO} (dBA) Peak	Comments	Location
							EAR MUFF - MARK IV								
1	Jack Leg Drill (L. Breault)	◒	13.5	115.3	15.8	4.8	10.3	120.4	139.0	115.0	116.5	116.2	131.0		2700 level
2	Stoper Dr. Rock Bltg. (G. Trottier)	◒	14.0	111.8	21.4	16.5	19.0	117.8	*142.1	113.4	115.2	115.5	132.3	Wide brim helmet (old style)	2600 level
3	Stoper Dr. Rock Bltg. (R. Auger)	◒	13.5	112.9	16.5	15.1	15.8	121.4	143.4	118.8	117.7	117.7	133.9		2700 level
4	Jumbo Drill (Elec. Hydr.) (G. Yarkie)	◒	14.0	107.2	*24.0	17.1	*20.6	110.8	125.0	109.2	107.5	108.3	121.4		2700 level
5	Long Tom Drill (2 boom) (R. Perreault)	◒	13.5	117.9	28.7	*16.2	*12.5	126.3	*148.0	121.5	122.1	121.6	137.5		2300 level
6	Long Tom Drill (2 boom) (B. Seguin)	○	14.5	115.0	13.3	*19.9	*16.6	-	--	122.5	121.5	122.7	136.6		2300 level
7	Diamond Drill (D. Kokkinson)	○	13.75	99.2	12.3	3.0	7.7	106.7	*122.1	97.4	100.1	99.8	111.9	Muff pads in bad shape	2625 level
8	Conveyorman (G. Brunelle)	◒	13.50	88.2	*7.1	9.3	8.2	97.9	*120.0	88.9	87.2	87.8	105.3	Wide brim helmet (old style)	3100 level
	Mean		13.78	107.50	18.00	11.30	13.20	114.19	135.80	110.84	110.98	111.20	126.24		
	Std. Dev.		0.36	10.47	6.13	6.82	5.13	10.14	9.61	11.96	12.09	12.02	12.07		
							EAR MUFF - PELTOR (H7)								
1	Long Tom Drill (P. Lafleur)	●	13.5	117.9	13.6	14.3	14.0	120.2	139.8	117.9	117.4	117.5	137.5	Muffs worn with band at nape of neck - no head strap	2700 level
2	Long Tom Drill (2 boom) (M. Pelletier)	◒	14.0	114.3	24.6	21.0	22.8	119.1	138.7	115.7	117.4	116.4	132.0		2500 level
							EAR MUFF - BILSOM								
1	ITH - In the Hole Drill (B. Leadbeater)	○	14.0	102.4	13.5	14.7	14.1	107.7	128.4	100.3	100.0	100.0	114.2	Uses plugs only - borrowed hat and muffs	

Note: ○ Satisfactory; ◒ Good, ● Very Good.

Undetermined numbers (*). and *No.) are not in Mean value.

Attenuation tests of different models of ear muffs - ISO mode

No.	Equipment	Comfort		L_{ISO} (dBA)	Attenuation (dB) L.S.	R.S.	[illegible]	L_{ISO} (dBA) Max	Peak	L_{OSHA} (8h) (dBA)	Comments	Location
						EAR MUFF - MARK IV						
1	Jackleg Drill (L. Breault)	◓	13.5	117.8	18.5	5.8	12.15	127.1	146.8	112.1		2700 level
2	Stoper Dr. Rock Bltg. (R. Auger)	◓	13.5	16.05	15.9	20.2	18.0	122.9	150.5	115.0		2760 level
3	Stoper Dr. Rock Bltg. (R. Seguin)	○	14.5	117.1	21.4	26.6	24.0	121.9	140.25	115.0		2125 level
4	Stoper Dr. Rock Bltg. (G. Trottier)	◓	14.0	109.9	22.0	11.9	16.95	121.1	151.25	-	Wide brim helmet (old style)	2600 level
5	Jumbo Drill (G. Yackle)	◓	14.0	108.25	11.2	21.8	17.5	112.8	127.0	107.4		2700 level
6	Long Tom Drill (R. Seguin)	○	14.5	121.0	23.6	26.9	25.15	122.9	140.5	115.0		2125 level
7	Long Tom Drill (La Pensee)	◓	14.5	121.0	19.6	15.6	17.6	121.9	140.25	115.0		2125 level
8	Long Tom Drill (R. Perrault)	◓	13.5	119.85	21.5	19.7	23.6	121.1	151.25	-		2300 level
9	Diamond Drill (D. Hookinson)	○	13.75	107.5	5.1	19.0	12.05	99.85	121.0	95.6	Muff pads in bad shape	2625 level
10	Conveyer Man (G. Brunelle)	◓	13.5	87.7	9.0	6.4	7.7	95.35	120.8	92.7	Wide brim helmet (old style)	1100 level
	Mean		13.91	112.65	17.84	18.56	18.22	119.95	140.23	101.95		
	Std. Dev.		0.44	10.14	5.76	7.22	4.54	8.48	5.81	9.28		
						EAR MUFF - PELTOR (H7)						
1	Long Tom Drill (M. Pelletier)	◓	15.0	115.2	24.8	21.1	21.95	120.4	139.[illegible]	112.8		2500 level
2	Long Tom Drill (P. Lafleur)	●	13.5	120.1	20.1	26.0	23.05	121.55	141.05	115.0	Muffs worn with band at nape of neck - no head strap	2700 level
						EAR MUFF - BILSOM						
1	Hole Drill ITH (B. Leadbetter)	◒	14.0	102.1	6.0	12.4	9.2	107.5	127.55	101.0	[illegible] plugs only - borrowed hat and muffs	2900 level

Note: ○ Satisfactory; ◓ Good; ● Very Good.

Undetermined numbers (No. and No.) are not in [illegible]

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Attenuation measurements of ear muffs

at Fraser Mine, 1984

1986

ATTENUATION MEASUREMENTS OF EAR MUFFS AT FRASER MINE 1984

by

M.U. Savich* and J.K. Weglo**

ABSTRACT

Ear muffs are the main protection of the mining workforce for the attenuation of noise.

The measurement of head size as against clamping force as well as the condition of the ear muffs are demonstrated as important variables in this attenuation of noise.

The "NO NOISE" ear muffs attenuation was about 13.3 dBA average with a Standard Deviation of 4.8 dBA at the Fraser Mine.

The Mark V ear muffs, replacing those in this study, based on clamping force measurements versus head size can be expected to produce attenuation >14 dBA.

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MESURE DU DEGRÉ DE RÉDUCTION DU BRUIT DES SERRE-TÊTES À LA MINE FRASER, 1984

par

M.U. Savich* et J.K. Weglo**

RÉSUMÉ

Les serre-têtes sont utilisés comme principale protection contre le bruit par les travailleurs des mines.

La mesure des dimensions de la tête par rapport au dispositif de fixation de même que la condition des serre-têtes sont des variables importantes de l'amortissement du bruit.

À la mine Frazer, le niveau d'amortissement "aucun bruit" des serre-têtes était en moyenne de 13,3 dBA et l'écart-type était de 4,8 dBA.

Les serre-têtes Mark V qui ont remplacé ceux qui avaient été utilisés aux fins de la présente étude et qui sont fabriqués d'après des critères de fixation par rapport aux dimensions de la tête auront probablement la capacité d'amortir le bruit à >14 dBA.

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INTRODUCTION

As part of the ongoing program of reducing noise pollution at Falconbridge Mines, measurements were performed to test the efficiency of ear muffs which were being used there.

At the Fraser Mine the following ear muffs were tested:

1) "NO NOISE", model NN3-F, the Hellberg Standard Volume Hearing Protector, hard hat attachment;
2) Mark IV, MSA, worn behind the head;
3) Mark V, Ear cup kit, MSA hard hat attachment;
4) David Clark, model E-705 straightaway;
5) Bilsom Viking muff 2314, hard hat attachment; and
6) Peltor H7P3e, hard hat attachment.

Most of the analyses were done on "NO NOISE" ear muffs, model NN3-F, because they were the ones most commonly used by over 90% of the workforce. The framework and method, followed by theoretical and practical considerations, are described in the main report and should be read to compare Fraser with other Falconbridge Mines.

Fifty-seven tests of head size and clamping force were made and 25 attenuation tests were performed on the "NO NOISE" ear muffs. On the Mark IV muffs 3 attenuation tests were done, and 2 such tests on David Clark muffs. Only one test was performed on each of the other brands. Attenuation characteristics of all ear muffs are given in Table 1. Noise Reduction Ratings (NRR) given in this Table are those supplied by manufacturers and from this data all muffs are approximately equal.

MEASUREMENTS AND RESULTS

Tests were performed using Metrosonics instrument, type db-307. The

Table 1 - Attenuation characteristics of ear muffs acquired for testing (ANSI S3.19-1974).

No.	Ear Muff	Characteristic	Frequency Hz									NRR
			125	250	500	1000	2000	3150	4000	6300	8000	
1	"NO NOISE" Model NN5-F Hellberg	Mean	16.2	19.9	25.2	34.1	36.0	39.2	39.0	40.3	38.1	24
		Std. Dev.	2.5	1.8	2.0	1.7	2.2	3.1	2.0	4.0	4.1	
2	Mark IV MSA	Mean	17.0	18.0	29.0	36.0	38.0	44.0	44.0	43.0	43.0	24
		Std. Dev.	2.6	2.6	3.1	3.2	4.1	7.2	4.6	4.7	5.7	
3	Mark V MSA Hard hat attachment	Mean	14.9	20.2	28.2	35.0	33.4	35.4	33.5	33.1	32.2	24
		Std. Dev.	2.6	1.5	1.9	2.5	2.1	2.8	2.6	2.7	3.0	
4	David Clark Model E-705 Straightaway	Mean	12.0	17.0	30.0	35.0	35.0	36.0	37.0	32.0	30.0	-
		Std. Dev.	2.5	3.0	4.6	5.6	4.5	4.3	4.2	4.1	2.9	
5	Viking Muff No. 2314 Bilsom	Mean	15.0	21.0	27.0	37.0	36.0	38.0	42.0	42.0	39.0	25
		Std. Dev.	1.8	2.0	2.5	2.8	1.5	2.3	3.0	3.7	3.6	
6	Peltor H7P3e	Mean	14.1	18.8	28.1	36.2	35.6	38.4	35.0	35.5	36.4	24
		Std. Dev.	2.1	2.0	3.0	2.1	2.2	2.3	2.1	2.1	2.4	

instrument measures sound over the continuous range of 45 to 140 dBA. Its microprocessor continuously samples and displays dBA sound levels while calculating L_{max}, L_{peak} and test duration. Testing should be done using 4 dosimeters rather than 3, as we have done. This would simplify and speed up testing time. It is very time-consuming and difficult to reset from OSHA (doubling at 5 dB) to ISO (doubling at 3 dB) in most work areas. Cables and microphones should be small in size in order to avoid creating an opening that would cause leakage of sound at the point where they enter the muff (breaking the seal between muff and face). It was found to be very difficult at times to position microphones comfortably inside ear muffs. Workers had a tendency to want to adjust their ear muffs while the test was being conducted which sometimes caused leakage and forced a repeat of the test.

Conducting tests on workers using fixed equipment (such as [I.T.H.] in the hole drills, jumbo drills and diamond drills) was much simpler, providing workers didn't encounter problems with their equipment and were willing to cooperate. Testing where workers use man-handling equipment such as jack legs - stopers, scooptrams and mucking machines was more difficult.

Head size was measured with outside calipers, and clamping force with a manual balance.

HEAD SIZE AND CLAMPING FORCE

Head size and clamping force tests were performed only on "NO NOISE" ear muffs. Summary results of head size and clamping force tests are in Appendix A.

The head size frequency curves of clamping force tests on population - 57, and of attenuation tests on population - 23, were constructed in Figure 1. On the basis of population - 57 data, a negatively skewed curve is obtained because heads in this sample were of consistently small bizygomatic diameter.

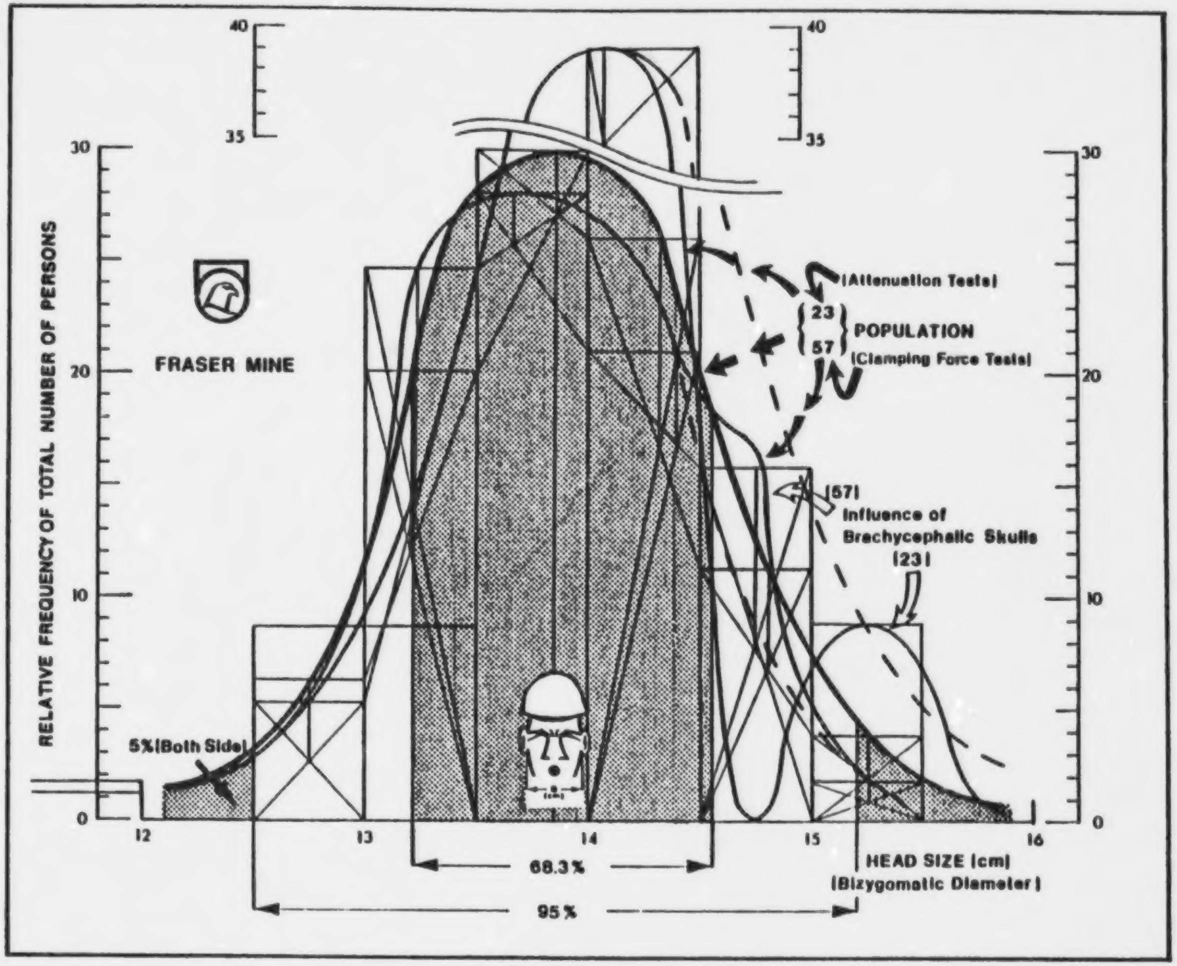

Fig. 1 - The normal symmetrical frequency of bell-shaped curve (population - 80) of head size tests. The negative skewness curve (population - 57) has a hump-influence of brachycephalic skulls. The bimodal frequency curve has two maxima (population - 23): the first maximum is typical positive skewness; and the second maximum is on large-sized heads.

The sample population contained many persons of French origin. Such people, specifically those whose ancestors came from Normandy and other Atlantic regions of France, tend to have small heads. A more marked variation of head dimensions occurs with a smaller population during attenuation tests. When test results are performed on a large population a normal symmetrical frequency, or bell-shaped curve, is obtained. Large population samples are necessary to allow proper evaluation.

By simply calculating the above-mentioned curve nuances cannot be noticed (Table 2).

Table 2 - Summary of head size tests

No.	Test	N	cm		Confidence Limit, cm	
			Mean	Std. Dev.	90%	95%
1	Head size and clamping force	57	13.64	0.77	13.64±0.16 cm	13.64±0.19 cm
2	Attenuation	23	13.76	0.62	13.76±0.22 cm	13.76±0.26 cm
1-2	Σ	80	13.67	0.73	13.67±0.13 dBA	13.67±0.15 dBA

Population → (N) Grand Mean ← (13.67)

In this Table we can see that confidence limits are high, and that at this mine heads of small bizygomatic diameter are most prevalent. Measurements of head size and clamping force were repeated twice because of the author's bias, which was formed on the basis of literature data and his own measurements (for North America the average head size is 14.35 cm).

The clamping force frequency curve has negative skewness (skewed to the left, but only slightly) (Figure 2). It can almost be said that the curve is symmetrically normal. From the clamping force frequency curve it can be concluded that 82% of the work force has a clamping force stronger than 1000 gwt, which is good as far as attenuation is concerned. Ear muff damage was

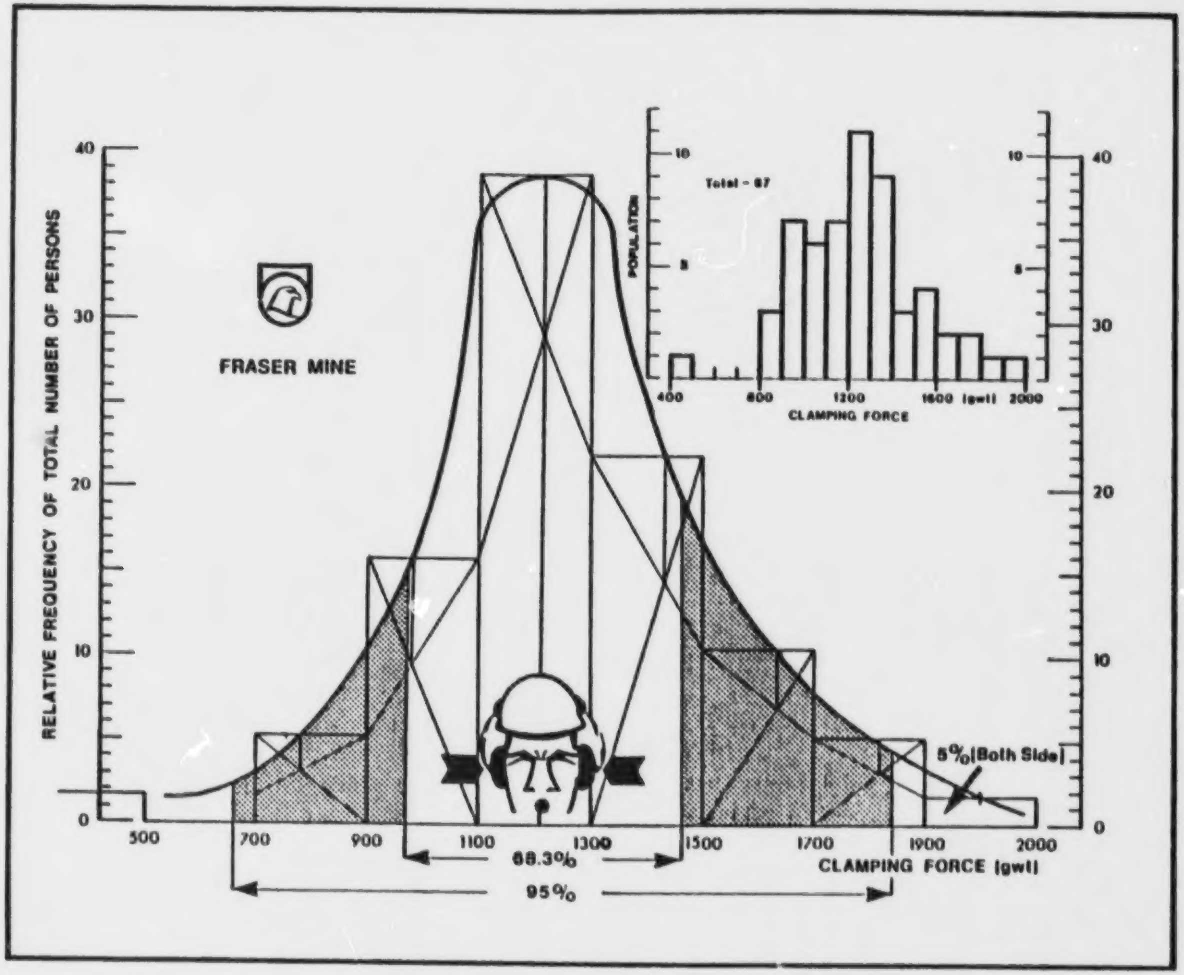

Fig. 2 - The clamping force frequency curve skewed to the right (positively skewed).

not heavy in relation to population, but was significant because of the high standard deviation (Figure 3). Most deterioration occurs with small heads (13.00 to 13.50 cm). These are two possible reasons for this: either ear muffs are not efficient on small heads, or clamping force is too strong, forcing workers to 'adjust' it for comfort, thus damaging muff springs. The second explanation is more likely, because standard deviation is high. The same thing occurs when head size is from 14.50 to 15.00 cm. Clamping force does not increase progressively with head size. Data from Appendix A was used to construct a standard deviation (error) ellipse (Figure 4). From this construction we can see that the ellipse in large part covers the field of clamping force versus head size; and therefore, we can expect good attenuation.

Utilization of the OSHA prescribed methods of estimating the adequacy of hearing protector attenuation, requires the availability of the manufacturers' published Noise Reduction Rating (NRR) and/or octave band attenuation data at the frequencies from 125 Hz to 8 kHz (1). This estimation method will be used in all reports. Results obtained will be compared with the results of measurements taken at this and other mines.

Condition of ear muffs were extremely good.

Ear Muffs	N*	Condition of Muffs					
		Good		Fair		Poor	
		N_1	Percent	N_2	Percent	N_3	Percent
"NO NOISE"	57	49	85.96	7	12.28	1	1.75

Note: * Population ($N^* = N_1 + N_2 + N_3$)

While tests were being done all minor damage was repaired and ear cushions were replaced.

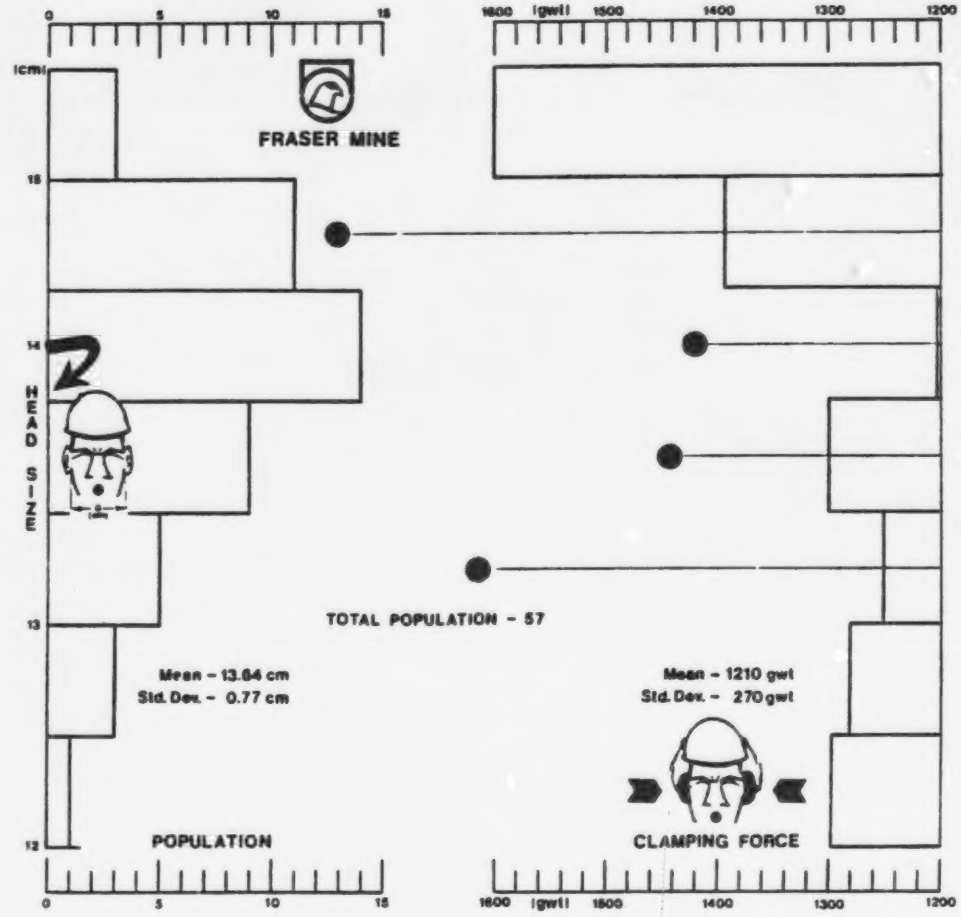

Fig. 3 - Relationships between head size and clamping force at the Fraser Mine.

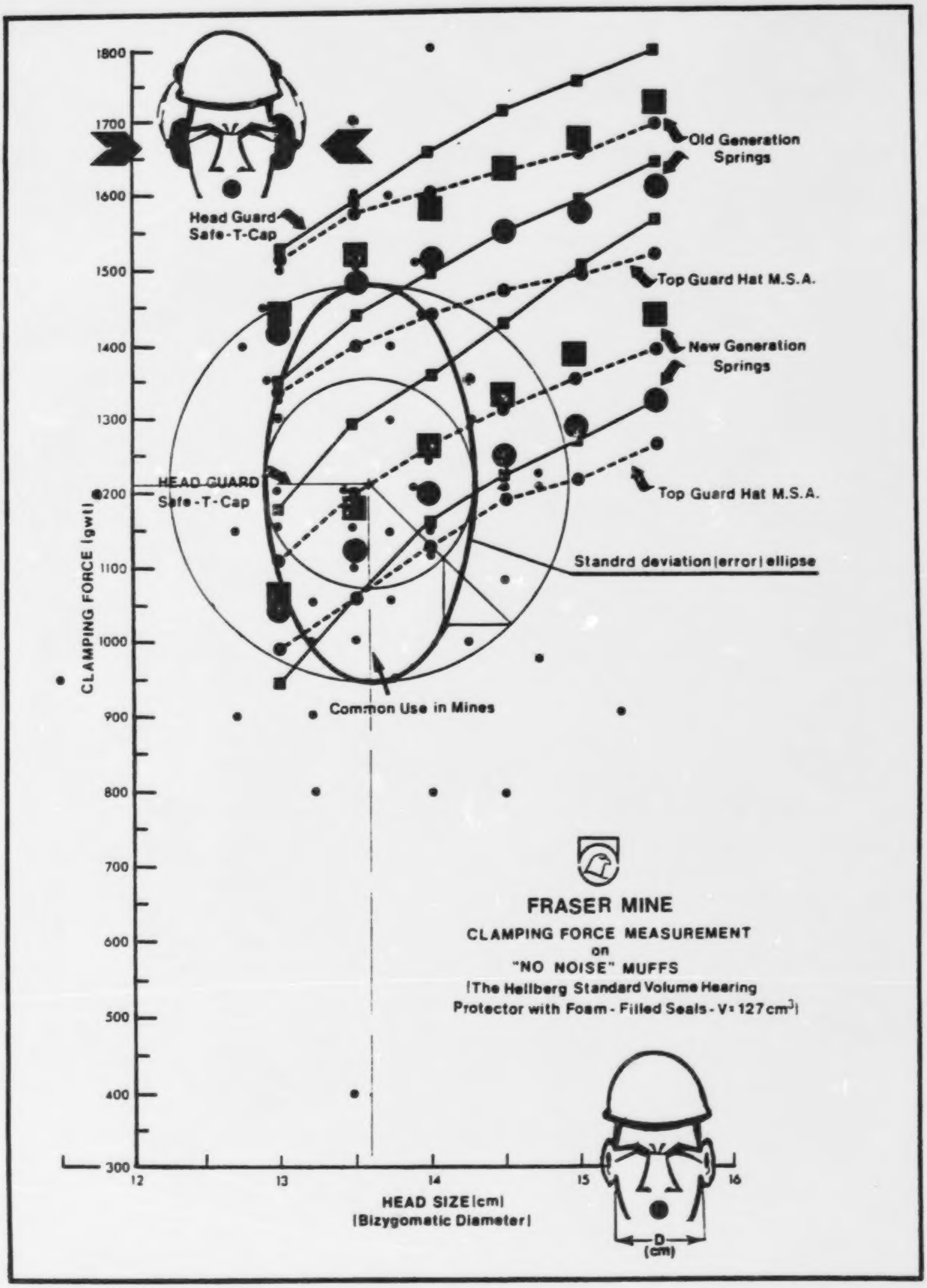

Fig. 4 - Standard deviation (error) ellipse of "NO NOISE" muffs.

ATTENUATION MEASUREMENTS

Attenuation measurements were performed on the following ear muffs:

1) "NO NOISE", model NN3-F, 25 measurements were made in OSHA mode, and 25 measurements in ISO mode (Appendices B and C);
2) Mark IV, MSA, 3 measurements in OSHA mode, and 3 measurements in ISO mode (Appendices D and E).
3) Mark V, MSA, 1 measurement in OSHA mode, and 1 meaurement in ISO mode (Appendices D and E).
4) David Clark, model E-705, 2 measurements in OSHA mode, and 2 measurements in ISO mode (Appendices D and E).
5) Bilsom Viking muff 2314, 1 measurement in OSHA mode, and 1 measurement in ISO mode (Appendices D and E).
6) Peltor H7P3e, 1 measurement in OSHA mode, and 1 measurement in ISO mode (Appendices D and E).

Testing was carried out on various types of equipment (e.g., Joy jacklegs and stopers, Gardner Denver jumbo drills, in-the-hole ITH drills, mucking machines and scooptrams. A total of 33 tests were conducted.

Tests of "NO NOISE" ear muffs show the following attenuations (Appendices B and C):

Mode	dBA		Confidence Limit	
	Mean	Std. Dev.	90%	95%
OSHA	12.68	6.82	12.68±2.32 dBA	12.68±2.80 dBA
ISO	13.29	4.83	13.29±1.69 dBA	13.29±1.98 dBA

In both modes we get results which are approximately equal. For the 90% ISO mode confidence limit, the result differs by ±1 dBA; and for the 95% limit there is essentially no difference between OSHA and ISO modes.

At the Fraser Mine almost 90% of the miners wear "NO NOISE" ear muffs, which have a small cup size. Workers with large ears, who are quite common, find microphones in their muffs very annoying and claim that they cause an increase in noise levels. It is important, when positioning a microphone in the muff, to take a noise reading (trial run) and re-adjust the muff if necessary. Workers should be instructed not to adjust their muffs until the test has been completed. At times when a worker is working hard physically (lots of bending and reaching) in operating his equipment, adjustment is more frequent and more leakage occurs. Other muffs, such as Mark IV, Mark V, David Clark, Bilsom and Peltor, have a large cup which helps to avoid this problem. Because of the small number of attenuation tests performed on these muffs, the muffs cannot be fully evaluated. All indications, however, are that they show better attenuations:

N	dBA		Confidence Limit	
	Mean	Std. Dev.	90%	95%
7	16.27	4.75	16.27±3.25 dBA	16.27±4.14 dBA

Population

From the 7 measurements carried out on the other types of ear muffs, we can see that the lowest values are 13.02 dBA (90% confidence limit) and 12.13 dBA (95% confidence limit), which is approximately the same as "NO NOISE" ear muffs. The highest values are 19.52 dBA (90% confidence limit) and 20.41 dBA (95% confidence limit), which is high if one considers that they have the same NRR as the "NO NOISE" model NN3-F ear muffs (Table 1).

Comfort did not receive all that good a rating. This is to be expected because the error ellipse points to a strong clamping force of ear muffs (Figure 4). Comfort results are given in Table 3. From these results the following can be concluded: 76% of workers deemed "NO NOISE" muffs to have satisfactory comfort. If we compare this figure to the error ellipse (Figure 4), we see that 80.6% of the ellipse's area covers the field of head size versus clamping force. Here too, comfort and clamping force do not go hand in hand, showing an increasing relationship:

"NO NOISE" Ear Muffs	Comfort	○ -Satisfactory 75.9%	◒ -Good 24.1%
	Area rating error ellipse	Non-Coverage 14.4%	Coverage 80.6%

The same conclusion was reached at Falconbridge and Strathcona Mines.

Measurement results from Appendices B and C, and the Lockerby Mine were used to compute L_{max} and L_{peak} levels which were then compared with measurement results from Falconbridge and Strathcona Mines (Table 4). Measurements at the latter two mines were performed with an integrating sound level meter, Brüel and Kjaer, type 2225. However, measurements at the Fraser and Lockerby Mines were performed with a Metrosonics db-307 instrument. Instrument control was done to find means of standard deviations of L_{max} and L_{peak} (accuracy of measurement field test). Results should be approximately the same. However, with Fraser and Lockerby Mines' measurements they differ considerably, by 7 dBA and do not allow for L_{peak} comparison. L_{ave} is measured well by the instrument (slow-speed chips).

In Appendix C the data shows how attenuation falls because of the slowness of the processing chips in the instrument.

N	Characteristic	Attenuation (dBA)		
		L_{ave}	L_{max}	L_{peak}
25	Mean Std. Dev.	13.29 4.83	11.45 4.72	9.03 8.94
25	Confidence Limit 90%	13.29±1.64	11.45±1.60	9.03±3.04
25	Confidence Limit 95%	13.29±1.98	11.45±1.93	9.03±3.65

↑ Population

Table 3 - Comfort of ear muffs in mines

No.	Ear Muff	N*	○-Satisfactory		◒-Good		●-Very Good	
			N_1	Percent	N_2	Percent	N_3	Percent
1	"NO NOISE" (NN3-F)	29	22	75.9	2	24.1	0	0.0
2	Mark IV MSA	3	2	66.7	1	33.3	0	0.0
3	Mark V MSA	1	0	0.0	1	100.00	0	0.0
4	David Clark Model E-705	2	0	0.0	1	50.0	1	50.0
5	Bilsom, Viking 2314	1	0	0.0	0	0.0	1	100.0
6	Peltor, H7P3e	2	0	0.0	1	100.00	1	0.0
1-6	Σ	38	24	63.2	11	28,9	3	7.9

Note: * Population ($N^* = N_1 + N_2 + N_3$)

Table 4 - Comparison of peak levels in the different mines using different instrumentation for evaluation

		Falconbridge - Strathcona Instrument: Bruel and Kjaer Integrating Sound Level Meter Type 2225.				Fraser - Lockerby Instrument: Metrosonics db-307 Noise Dosimeter and Integrating Sound Level Meter.				
		dBA				dBA				
No.	Sound Source	L_{max} Mean Std. Dev.	L_{peak} Mean Std. Dev.	Δ	N	L_{max} Mean Std.Dev.	L_{peak} Mean Std.Dev.	Δ	N	Comments
1	Jack Leg Drill	118.65 3.36	134.85 5.68	16.3	11	121.43 2.35	148.0 0.0	26.6	9	In Mean$_{SD}$, value not included
2	Stoper Drill - Rock Bolter	118.51 5.92	135.0 7.0	16.5	22	118.48 1.65	141.92 6.22	23.4	18	
3	Jumbo Drill - two booms	116.96 5.91	122.14 5.91	15.19	8	109.02 1.03	136.85 10.47	27.8	15	
4	Long Hole Drill	119.19 1.98	135.08 2.59	15.89	4	116.06 2.79	141.12 6.87	25.06	5	
5	Long Tom Drill - two booms	120.27 2.99	137.17 4.63	16.9	23	-	-	-	-	
6	ITH In the Hole Drill	98.27 5.12	116.25 5.66	17.98	7	101.06 5.79	121.65 18.36	20.59	37	
7	Diamond Drill	104.02 4.76	120.81 9.93	16.79	7	108.6 1.77	133.74 11.90	25.14	18	
8	Mucking Machine	106.58 3.60	121.53 3.53	14.95	4	109.97 0.51	147.26 1.18	37.29	5	
9	Bolting Machine	-	-	-	-	110.55	147.0	36.4	1	
10	Air Plugger (Brk. Cement)	-	-	-	-	112.20 0.57	148.0 0.0	35.8	2	In Mean$_{SD}$, value not included
11	Slusher	97.50 4.99	111.35 4.45	13.85	4	115.30 1.27	148.0 0.0	32.7	2	In Mean$_{SD}$, value not included
12	Scooptram	106.55 14.57	123.33 11.80	16.78	12	108.18 5.22	142.12 9.38	33.94	16	
13	Conveyor Man	94.83 6.40	112.15 8.35	17.32	3	-	-	-	-	
14	Chute Puller	114.80 9.19	133.15 3.32	18.35	2	-	-	-	-	
15	Vent. Fan - 38" 60 HP	-	-	-	-	100.48 5.10	117.91 16.12	17.43	4	
16	Primary Crusher - C/G Jaw Crush.	102.34 6.93	121.56 8.24	19.22	8					
17	Secondary Crusher	91.77 1.33	106.27 1.62	14.5	3					
18	Tertiary Crusher	95.45 0.21	108.35 0.64	12.9	2					
19	Ball Mill	93.20 2.02	107.57 1.16	14.37	3					
20	Flotation Op. Area	85.9	99.3	13.4	1					
21	Compressor Room	89.7	103.0	13.3	1					
22	Power House	94.5	107.5	13.0	1					
23	Electrostatic Precipitator	93.65 0.35	109.20 3.82	13.55	2					
24	Converter Puncher	99.13 1.10	114.27 1.79	13.14	3					
25	Converter Skimmer - Fluxing	89.47 4.76	103.82 4.91	14.36	3					

Fraser - Lockerby:

	Mean$_{SD}$ Std.Dev.	Mean$_{SD}$ Std.Dev.	
○ 8	2.98 2.09	9.81 5.25	8 ○

Falconbridge - Strathcona:

	Mean$_{SD}$ Std.Dev.	Mean$_{SD}$ Std.Dev.	
○ 19	4.51 3.45	5.00 3.04	19 ○

Laboratory tests of measurement accuracy were performed at Laval University and their conclusion agrees with the one above (2). This explains why L_{max} and L_{peak} of Fraser and Lockerby Mines were not presented to the main report for Falconbridge Ltd.

CONCLUSIONS

Measurements have shown that the attenuation of "NO NOISE" ear muffs was about 13 dBA. Ear muff efficiency depends on the frequency range of noise. The overall condition of ear muffs was satisfactory because only 2% of them were deemed to be in poor condition. Workers should continue to be trained to understand the importance of a proper fit for ear muffs. Head shapes and sizes had a marked effect on attenuation. Physical obstructions, such as eye glasses and large ears decreased attenuation. From the attenuation measurements it can be concluded that ear muffs in themselves are not a complete solution to the attenuation of the noise level in the mining environment.

Ear muff control should be continued, by measuring head size and clamping force with the apparatus suggested in the main report.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the help and cooperation of E. Isaacs, Director, and P. Savalas, Field Technician of M.A.P.A.O. as well as J.A. Riddell, Mine Superintendent, Dr. A.G. Cecutti, Medical Director, and D. McPhee and R. Desjardins, Technicians, Falconbridge Ltd.

Acknowledgement is extended to J. Vergunst, Working Environment Engineer, Ontario Ministry of Labour, Sudbury, and R. Pleasance, Branch Manager, Levitt Safety (Metrosonics Inc.), Sudbury, for the loan of instruments.

Thanks are extended to G. Knight for reviewing the manuscript and making numerous helpful suggestions.

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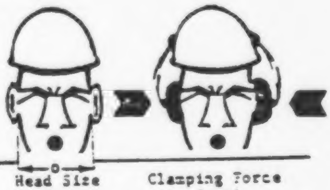
2. Archambault, R., Private communication; 1985.

Head size and clamping force data of "NO NOISE", Model NN3-F ear muffs.



No.	Occupation	Condition	Head Size (cm)	Clamping Force (gwt)
1	Driller	1	11.75	1200
2	Driller	1	11.50	950
3	Driller	1	11.25	1200
4	Driller	1	14.25	1350
5	Driller	1	13.00	1350
6	Driller	1	13.50	1200
7	Driller	1	13.25	1050
8	Driller	2	13.75	950
9	Driller	1	13.50	1700
10	Driller	1	14.50	1400
11	Driller	1	13.00	1300
12	Raise Driller	1	13.25	1325
13	Raise Driller	1	13.25	1325
14	Raise Driller	1	13.25	1150
15	Blast Hole Drill.	1	14.25	900
16	DTH Drill.	1	13.00	1500
17	Diamond Drill	3	13.50	400
18	Diam. Drill Form.	1	15.25	900
19	Long Hole Blast.	1	14.00	1200
20	Blaster Helper	1	13.75	1150
21	Gunite Operator	1	13.75	1300
22	Gunite Operator	1	13.25	1000
23	Gunite Operator	1	14.50	800
24	Gunite Operator	2	14.00	1100
25	Nipper	1	14.00	1500
26	Trammer	1	13.00	1450
27	Trammer	1	13.50	1500
28	Trackman	1	13.00	1300
29	Pipe Fitter	1	14.25	1300
30	Pipe Fitter	1	13.50	1700
31	Scooptram Op.	2	12.75	900
32	Scooptram Op.	1	14.75	1225
33	Scooptram Op.	1	14.50	1150
34	Scooptram Op.	2	14.00	1250
35	Scooptram Op.	2	14.00	800
36	Construction	2	13.50	1100
37	Construction	1	14.75	975
38	Construction	1	13.25	1000
39	Construction	1	14.50	1200
40	Construction	1	13.50	1600
41	Construction	1	14.00	1900
42	Construction	1	14.50	1200
43	Construction	1	13.50	1700
44	Lev. Cleaner	1	13.25	800
45	Lev. Cleaner	1	13.75	1400
46	Lev. Cleaner	1	14.75	1200
47	Cage Tender	2	14.25	1000
48	Cage Tender	1	13.75	1600
49	Training	1	13.50	1150
50	Training	1	13.25	900
51	Shift Boss	1	14.00	1500
52	Shift Boss	1	13.75	1050
53	Shift Boss	1	13.00	1200
54	Shift Boss	1	12.75	1100
55	Safety Superv.	1	13.50	1200
56	Ground Control	1	14.50	1900
57	Ventilation	1	14.25	1350
	Mean:		13.64	1210
	Std. Dev.:		0.77	270

Note: 1 - Good; 2 - Fair; 3 - Poor.

Attenuation tests of "NO NOISE" model NN3-F muffs in OSHA mode.

No.	Equipment	Comfort		L. Avg. (dBA)	Attenuation (dBA)			L. Max. (dBA)	Attenuation (dBA)			L. Peak (dBA)	Attenuation (dBA)			Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.		L.S.	R.S.	B.S.	
1	Jack Leg AL-60 Drill	○	14.0	116.85	7.0	2.9	4.95	120.1	7.7	2.8	5.25	148.0	4.3	11.4	7.85	3400 Level, 2-560 Stope
2	Stoper Dr.-Rock Bltg.	◒	13.5	113.5	13.8	9.7	11.75	119.4	7.8	4.5	6.15	136.2	3.4	6.1	4.75	3300 Level, Sublevel
3	Stoper Dr.-Rock Bltg.	○	-	107.15	14.9	4.3	9.6	116.15	10.3	2.2	6.25	135.15	3.1	-	1.55	3400 Level, 547-1 Stope
4	Stoper Dr.-Rock Bltg.	○	-	110.65	7.4	8.6	8.0	117.9	8.1	18.4	13.25	148.6	18.9	16.3	17.6	2900 Level, 285 Vent. Drift
5	Stoper Dr.-Rock Bltg.	○	-	116.5	12.6	2.7	7.3	120.[illegible]	15.4	1.3	8.35	148.0	17.7	7.1	12.4	2900 Level, 285 Vent. Drift
6	Jumbo Drill	◒	12.75	103.8	12.8	20.6	16.7	107.7	12.7	18.4	15.55	127.5	5.0	4.3	4.65	3300 Level, 552-54 Stope
7	Jumbo Drill	○	13.75	105.25	26.6	24.3	25.45	109.75	11.8	25.4	18.6	139.0	5.3	15.9	10.6	3400 Level, 558 Stope
8	Jumbo Drill	○	14.25	105.9	23.8	19.8	21.8	108.95	25.2	18.4	21.8	135.95	3.9	15.3	9.6	3400 Level, 558 Stope
9	Jumbo Drill	○	13.0	106.2	23.2	10.7	11.45	108.3	12.0	9.6	10.8	148.0	26.3	24.3	25.3	3400 Level, 543 Stope
10	Jumbo Drill	◒	14.0	102.5	4.2	5.3	4.7	109.35	8.0	9.5	8.75	148.0	25.2	26.0	25.6	3300 Level, 556 Stope
11	Jumbo Drill	○	14.0	105.3	18.0	10.0	14.0	109.1	21.6	9.7	15.65	141.05	16.7	13.6	15.15	3300 Level
12	Long Hole Drill ITH	◒	13.5	94.6	16.9	20.2	18.6	95.0	7.5	3.5	5.5	121.5	0.9	1.8	1.35	3400 Level, Waste Pass
13	Long Hole Drill ITH	○	13.5	94.5	26.1	5.4	15.7	97.25	9.0	6.2	7.6	148.0	26.0	22.6	24.3	3300 Level,302 Sublevel,556 Over Cut
14	Diamond Drill	◒	14.25	104.9	1.1	0.9	2.0	110.4	4.2	1.9	3.05	129.0	5.1	3.4	4.25	3300 Level,1 Cross Cut,Cl. Force 400 gwt.
15	Diamond Drill	◒	12.5	104.3	28.6	21.7	25.15	107.3	18.5	8.0	13.25	120.3	0.5	0.2	0.35	300 Level, 287 E. Drift
16	Diamond Drill	○	11.75	103.9	25.5	29.8	27.6	106.85	10.6	18.3	14.45	122.3	-	4.6	2.3	3300 Level, 287 E. Drift
17	Diamond Drill	○	-	109.0	13.4	14.9	14.1	112.0	9.2	1.9	5.55	124.2	1.0	3.1	2.05	3300 Level, 275 Drift
18	Diamond Drill-Foreman	○	15.0	104.85	11.7	8.7	10.5	108.7	8.[illegible]	3.3	5.75	123.3	0.7	3.8	2.5	3300 Level,1 Cross Cut,Cl. Force 900 gwt.
19	Air Plugger(Bck.Cement)	○	13.5	106.3	7.6	8.1	7.8	111.85	6.4	5.9	6.15	148.0	19.7	16.4	18.05	3400 Level Station
20	Bolting Machine	○	13.25	104.1	22.9	10.1	16.5	106.25	11.0	10.4	10.7	144.0	20.0	11.7	10.85	3400 Level, 360 Stope
21	Mucking Machine	○	-	99.5	5.9	10.0	7.9	110.55	4.5	8.2	8.95	147.0	12.1	13.3	12.7	2900 Level, Vent. Drift
22	Scooptram S.T. 8	○	14.0	96.2	9.6	8.0	8.8	104.45	5.3	5.5	5.4	132.6	2.6	4.4	3.5	3400 Level, 564 Over Cut
23	Scooptram S.T. 8	○	14.25	97.2	8.0	7.6	7.8	105.4	8.3	6.5	7.4	130.15	5.9	0.4	3.15	3400 Level, 564 Over Cut
24	Scooptram S.T. 8	○	-	97.2	7.2	9.5	8.3	105.85	7.3	7.7	7.5	148.0	20.2	20.1	20.15	3400 Level, 552-2 Stope
25	Vent.Fans 38" 1.0 H.P.	○	13.75	95.1	13.3	7.8	10.55	96.8	4.9	4.3	4.6	96.75	2.9	8.8	5.85	3400 Level, 34-278 Ramp
	Mean:		13.71	104.11	14.04	11.24	12.68	109.04	10.22	8.47	9.45	135.6	9.9	10.20	9.86	
	Std. Dev.:		0.58	6.12	7.71	7.63	6.82	6.64	5.19	6.47	4.82	12.94	9.2	7.89	8.08	

Note: ○ Satisfactory; ◒ Good; ● Very Good.

Attenuation tests of "NO NOISE", model NN3-F muffs in ISO mode.

No	Equipment	Comfort		L Avg. (dBA)	Attenuation (dBA)			L Max. (dBA)	Attenuation (dBA)			L Peak (dBA)	Attenuation (dBA)			Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.		L.S.	R.S.	B.S.	
1	Jack Leg AL-60 Drill	○	14.0	120.6	14.3	8.6	11.4	121.6	14.1	7.0	10.55	140.8	7.4	3.6	5.5	3400 Level, 2-560 Stope
2	Stoper Dr.-Rock Bltg.	◒	13.5	-17.3	13.9	21.4	17.6	119.5	14.1	19.3	16.7	137.4	8.3	13.0	10.65	3300 Level, sub-level
3	Stoper Dr.-Rock Bltg.	○	-	114.8	20.1	17.4	18.7	119.2	10.3	11.6	10.8	135.9	10.0	5.2	7.6	3400 Level, 547-1 Stope
4	Stoper Dr.-Rock Bltg.	○	-	112.9	4.0	6.4	5.2	117.5	9.3	5.6	7.45	148.0	22.2	15.2	18.7	2900 Level, 285 Vent. Drift
5	Jumbo Drill	◒	12.75	110.0	14.2	13.8	14.0	107.8	12.2	12.9	12.5	123.6	3.2	4.4	3.8	3300 Level, 552-54 Stope
6	Jumbo Drill	○	13.75	104.6	20.1	20.7	20.4	107.8	20.0	19.5	19.75	121.0	0	0	0	3400 Level, 558 Stope
7	Jumbo Drill	○	14.25	106.7	14.8	20.7	17.7	108.2	19.1	17.4	18.25	128.7	8.4	4.3	6.35	3400 Level, 558 Stope
8	Jumbo Drill	○	13.0	106.5	12.8	16.8	14.8	109.95	14.6	13.2	13.9	148.0	26.3	28.0	27.15	3400 Level, 543 Stope
9	Jumbo Drill	◒	14.0	104.2	13.3	9.6	11.4	110.1	5.0	11.9	8.4	148.0	27.6	28.0	27.8	3300 Level, 556 Stope
10	Jumbo Drill	○	14.0	105.5	19.8	9.7	14.7	109.3	11.2	10.9	11.0	126.6	9.0	4.3	6.6	3300 Level
11	Jumbo Drill	○	15.5	107.5	19.0	23.9	21.2	111.5	17.6	23.0	20.3	124.8	2.4	0	1.2	3300 Level, 552-54 Stope
12	Long Hole Drill I.T.H.	◒	13.5	91.3	3.8	5.5	4.6	93.7	5.4	6.0	5.7	120.0	0	0	0	3400 Level, Waste Pass
13	Long Hole Drill I.T.H.	○	13.5	95.2	13.2	19.4	16.3	97.5	10.4	11.0	11.2	120.3	1.8	4	2.9	3400 Level, Waste Pass
14	Long Hole Drill I.T.H.	○	13.75	97.3	17.1	15.0	16.0	99.65	12.4	14.1	13.25	142.3	27.0	24.2	25.6	3400 Level, 556 Over Cut
15	Diamond Drill	◒	14.25	105.6	8.4	4.1	6.2	108.9	5.2	-	2.51	123.4	+1.7	+3.2	+2.45	3300 Level,1Cross Cut, Cl.Force 400 gwt.
16	Diamond Drill	◒	12.5	102.9	18.6	23.9	21.2	107.1	18.7	19.4	19.05	124.3	1.9	5.8	3.85	3300 Level, 33-287 E. Drift
17	Diamond Drill	○	13.75	103.5	17.9	7.1	12.5	107.2	17.1	9.2	13.6	120.4	0	0.8	0.4	3300 Level, 33-287 E. Drift
18	Diamond Drill	○	-	108.3	11.5	13.9	12.7	113.3	7.8	14.6	11.2	126.9	0.2	2.9	1.55	3300 Level, 275 Drift
19	Air Plugger(Brk.Cement)	○	13.5	109.8	5.5	10.7	10.1	112.6	8.4	11.5	9.95	148.0	19.2	22.2	20.7	3400 Level, Station
20	Mucking Machine	◒	-	100.5	12.1	13.0	12.5	109.3	5.5	3.9	4.7	148.0	5.1	12.7	8.9	2900 Level, Vent. Drift
21	Mucking Machine	○	-	101.3	7.7	[illegible]	[illegible]	110.2	5.8	[illegible]	6.5	148.0	8.7	13.5	11.1	2900 Level, Vent. Drift
22	Scooptram S-T-8	○	14.0	96.8	9.9	6.6	8.2	96.0	10.4	11.0	10.7	120.4	1.8	4.0	2.9	3400 Level, 564 Over Cut
23	Scooptram S-T-8	○	14.25	98.8	10.5	7.4	8.9	105.3	7.2	5.6	6.4	129.8	2.4	0.4	1.4	3400 Level, 564 Over Cut
24	Scooptram S-T-8	○	-	100.0	11.9	9.3	10.6	107.0	11.1	8.8	9.95	148.0	13.2	20.6	16.9	3400 Level, 552-2 Stope
25	Vent Fans 38" 60 H.P.	○	13.75	93.9	17.4	15.9	16.6	95.4	13.1	10.8	11.95	125.2	6.3	4.1	5.2	3400 Level, 34-278 Ramp
Mean:			13.76	104.6	13.43	13.22	13.29	108.3	11.46	11.42	11.45	133.11	8.58	9.24	9.03	
Std. Dev.:			0.64	7.24	4.68	6.03	4.83	7.54	4.64	5.47	4.72	11.24	9.06	9.22	8.94	

Note: ○ Satisfactory; ◒ Good; ● Very Good.

Attenuation tests of different models of ear muffs in OSHA mode.

No.	Equipment	Comfort		L. Avg. (dBA)	Attenuation (dBA)			L. Max. (dBA)	Attenuation (dBA)			L. Peak (dBA)	Attenuation (dBA)			Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.		L.S.	R.S.	B.S.	
								EAR MUFF - MARK IV								
1	Stoper Dr.-Rock Bltg.	◒	-	108.35	13.4	13.4	13.4	115.8	10.3	0.7	5.5	131.8	1.0	0.5	0.75	3400 Level, 567-1 Stope
2	Stoper Dr.-Rock Bltg.	◒	-	112.0	16.2	13.9	15.0	116.6	13.5	12.8	13.15	148.0	11.3	20.5	15.90	--
3	Vent. Fans, 38" 60 H.P.	●	14.0	101.7	23.2	24.8	24.0	104.35	17.4	20.5	18.95	124.3	4.3	6.3	5.3	3400 Level, Ramp
								EAR MUFF - MARK V								
4	Jumbo Drill	◒	14.0	105.6	14.0	22.4	21.5	108.7	20.2	22.4	21.3	148.0	17.5	24.4	20.95	3400 Level, 543 Stope
								EAR MUFF - DAVID CLARK								
5	Jack Leg AL-60 Drill	◒	-	109.8	19.5	10.7	15.1	118.15	16.3	11.8	14.05	148.0	14.6	10.5	12.55	3900 Level, Vent. Drift
6	Diamond Drill	●	15.0	106.45	19.5	22.8	21.1	109.15	6.2	18.0	12.1	124.5	4.4	4.6	4.5	3100 Level, 1 Cross Cut
								EAR MUFF - BILSOM								
7	Scooptram S.T. 8	●	13.5	97.4	17.9	15.8	16.8	106.3	6.9	9.1	8.0	148.0	7.6	20.0	13.8	3400 Level, 564 Stope
								EAR MUFF - M.S.A. PELTOR (H7)								
8	Mucking Machine	◒	-	97.05	9.7	19.1	14.4	110.2	7.8	17.9	12.85	148.0	10.8	10.9	10.85	

Note: ○ Satisfactory; ◒ Good; ● Very Good.

Attenuation tests of different models of ear muffs in ISO mode.

No.	Equipment	Comfort		L. Avg. (dBA)	Attenuation (dBA)			L. Max. (dBA)	Attenuation (dBA)			L. Peak (dBA)	Attenuation (dBA)			Location
					L.S.	R.S.	B.S.		L.S.	R.S.	B.S.		L.S.	R.S.	B.S.	
								EAR MUFF - MARK IV								
1	Stoper Dr.-Rock Bltg.	◒	-	113.1	16.1	17.6	16.8	119.2	15.9	15.9	15.9	134.2	9.9	5.2	7.55	3600 Level, 547-1 Stope
2	Stoper Dr.-Rock Bltg.	◒	-	110.0	9.1	8.8	8.9	115.2	11.6	7.0	9.3	143.65	7.2	15.0	11.00	3600 Level
3	Vent. Fans, 38" 60 HP	●	14.0	100.1	18.1	19.0	18.5	105.25	11.6	18.3	14.95	125.35	9.3	0.6	4.99	3400 Level, Ramp
								EAR MUFF - MARK V								
4	Jumbo Drill	◒	14.0	104.5	20.8	23.5	22.1	108.8	23.4	19.8	21.6	144.6	27.0	13.6	20.3	3400 Level, 543 Stope
								EAR MUFF - DAVID CLARK								
5	Jack Leg A.-60 Drill	◒	-	114.15	18.5	21.2	19.8	120.0	17.2	22.2	9.6	148.0	9.8	5.4	7.6	3900 Level, Vent. Drift
								EAR MUFF - BILSOM								
6	Scooptram S.T. 8	●	13.5	120.0	10.8	15.2	13.0	103.65	9.4	14.0	11.7	148.0	19.1	14.1	16.6	3400 Level, 564 Stope
								EAR MUFF - M.S.C. PELTOR (H7)								
7	Mucking Machine	◒	-	99.85	11.7	17.9	14.8	109.6	8.3	2.4	5.35	145.3	9.0	9.6	9.3	2900 Level, Vent. Drift

Note: ○ Satisfactory; ◒ Good; ● Very Good.

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86-88 M.U. Savich and J.K. Weglo

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1986

Published in CIM Bulletin 79 (894): pp 36-49 (1986)

MINE SAFETY

Attenuation measurements of ear muffs at Falconbridge Limited, Canadian Nickel Division, Sudbury Operations, 1984

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ABSTRACT

At the Falconbridge Limited, Canadian Nickel Division, Sudbury Operations, we investigated the "NO NOISE" ear muffs model NN3-F which is a Swedish product with foam-filled sealing rings (the Hellberg Standard Volume Hearing Protector). It is used extensively at Falconbridge mines in Sudbury.

The research which was carried out in the four Falconbridge mines was conducted under three different headings: manufacturer's attenuation data (psychophysical method), clamping force and head size (bizygomatic diameter), and attenuation tests (physical methods) under working conditions.

Manufacturers of hearing protectors claim their products offer noise reductions of 23 decibels (NRR) or more, but they fail to point out that this reduction is obtainable only under ideal conditions. The reality of attenuation under working conditions, as several studies have found, is quite different.

Methods for using short measurements to determine the noise exposure index, and for controlling muff-wearing habits, were developed at the Elliot Lake Laboratory. Measurements taken at Falconbridge on "NO NOISE" ear muffs revealed that they have a practical attenuation of some 10 to 13 decibels. It is important to note here that measurements also revealed that clamping force (thus attenuation) was in an inverse relationship with ear muff comfort. Measuring attenuation using noise dosimeters was a difficult job. Not a single surveyor would accept these measurements (physical method) for absolute accuracy. Apart from that, it was impossible to measure, in one

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Miron U. Savich obtained a Dipl. Eng. degree in mining at Ljubljana University (Yugoslavia) in 1953. He worked for Trepca Mines and was chief engineer at the Yugoslavian federal government Department of Geology. He joined the "Rudnik (Mining) Project" as senior project engineer in 1958. From 1962 to 1966, he was involved in the organization of research laboratories in mining and metallurgy. He then went to Sweden and worked on vibration techniques, defectoscopy and welding.

Mr. Savich emigrated to Canada in 1967. Working at McGill University's Institute of Mineral Industry Research, St. Hilaire, he constructed an anechoic chamber for the measurement of noise from hammer drills. He received an M.Eng. degree from McGill in 1972. After graduation, he joined the Elliot Lake Laboratory, Mining Research Laboratories, Canada Centre for Mineral and Energy Technology (CANMET), Energy, Mines and Resources Canada, Elliot Lake, Ontario.

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Keywords: Mine safety, Attenuation, Ear muffs, Noise, Clamping force, Head size, Falconbridge Limited.

Paper reviewed and approved for publication by the Maintenance/Engineering Division of CIM.

shift, more than two work stations. Because of this, we sought a solution: measuring head size and clamping force in relation to actual attenuations.

A detailed analysis of the relationship between attenuation and head size/clamping force was done at four mines. Standard deviation ellipses (standard error ellipses) for head size versus clamping force are in close agreement with measurements that were carried out. In order to measure clamping force an apparatus was constructed and a method for measuring suspension system durability is described in Appendices B and C of this report. At the same time we sought to reduce deterioration of ear muffs in mines as well as to put in place a system whereby attenuation can be controlled and improved. The clamping force apparatus can be operated automatically. The proposed control system is quick, simple and efficient. This system is equally applicable in small and large mining operations, and it can be totally automated and the data computerized for audit of the results. This control system is a new step in controlling ear muff attenuation in working environments.

From these measurements of NN3-F "NO NOISE" muffs it can be concluded that ear muffs are not the total solution to protect the worker from noise.

As the results were evaluated following measurement, Falconbridge switched from the NN3-F "NO NOISE" muffs to approximately 90% Mark V "NO NOISE" muffs and 10% Mark V MSA muffs. These new muffs showed much better head size versus clamping force relationship and can be expected to produce 14 dBA or better attenuation of noise.

RESUME

Une étude des casques antibruit "NO NOISE" modèle NN3-F, de fabrication suédoise, avec anneaux d'étanchéité en mousse (dispositif de protection contre le bruit "Hellberg" pour volume ordinaire) a été effectuée à la Falconbridge Ltd., Division canadienne du nickel aux installations de Sudbury. Ces casques sont largement utilisés dans les mines de la Falconbridge à Sudbury.

Cette étude a eu lieu en milieu de travail dans les quatre mines de la Falconbridge sous trois rubriques différentes soit: les données d'atténuation du bruit du fabricant (méthode psychophysique), la force de serrage et la taille de la tête (diamètre bizygomatique), et les essais d'atténuation de bruit (méthodes physiques).

Les fabricants de dispositifs de protection contre le bruit prétendent que leurs produits offrent une réduction du bruit s'élevant à 23 décibels (NRR) ou plus, mais ils négligent de souligner que cette réduction est obtenue dans des conditions idéales seulement. En réalité, tel qu'observé au cours de plusieurs études, le niveau d'atténuation du bruit obtenu dans le milieu de travail est très différent.

Des méthodes visant à utiliser de courtes mesures pour déterminer l'indice d'exposition au bruit et à contrôler les habitudes du port des casques antibruit ont été élaborées au Laboratoire d'Elliot Lake. Les mesures effectuées sur les casques antibruit "NO NOISE" à la Falconbridge ont démontré qu'ils offrent une atténuation pratique du bruit de 10 à 13 décibels environ. Il est important de souligner ici que les mesures ont aussi indiqué que la force de serrage (par conséquent l'atténuation du bruit) était à l'ordre inverse du confort des casques antibruit. La détermination de l'atténuation du bruit à l'aide d'appareils de mesure du bruit s'est avérée une tâche difficile. Aucun technicien n'a voulu accepté ces mesures (méthode physique) comme étant exactes. De plus, il a été impossible de mesurer plus de deux postes de travail au cours d'une période de travail. En raison de cette difficulté, nous avons cherché une solution, soit de mesurer la taille de la tête et la force de serrage par rapport aux atténuations réelles du bruit.

Une analyse détaillée du rapport entre l'atténuation du bruit de la taille de la tête/force de serrage a été effectuée dans les quatre mines. L'écart type des ellipses (erreur type des ellipses) pour la taille de la tête par rapport à la force de serrage se rapproche des mesures effectuées dans les mines. On a conçu, de plus, un appareil dans le but de mesurer la force de serrage, et une méthode servant à mesurer la durabilité du système de suspension est décrite dans les annexes B et C du présent rapport. Nous avons essayé, par la même occasion, de réduire la détérioration des casques antibruit dans les mines et de mettre en place un système permettant de contrôler et d'améliorer l'atténuation du bruit. L'appareil réglant la force de serrage peut être actionné automatiquement. Le système de contrôle proposé est rapide, simple et efficace. Ce système de contrôle peut être utilisé tant dans les petites que dans les grandes installations minières, et il peut être totalement automatisé et les données obtenues mises sur ordinateur pour permettre la vérification des résultats. Ce système de contrôle est un nouveau moyen permettant de contrôler l'atténuation du bruit offerte par les casques antibruit dans le milieu de travail.

On peut donc déduire des mesures obtenues pour les casques antibruit NN3-F "NO NOISE" que ces derniers ne sont pas le seul moyen disponible pour protéger les travailleurs contre le bruit.

Enfin, durant l'évaluation des mesures obtenues, la Falconbridge a échangé les casques antibruit NN3-F "NO NOISE" contre environ 90% de casques MARK V "NO NOISE" et 10% de casques MARK V MSA. Ces nouveaux casques donnent un meilleur rapport entre la taille de la tête et la force de serrage et peuvent fournir une atténuation de bruit de 14 dBA et plus.

Introduction

At the Falconbridge Limited, Canadian Nickel Division, in Sudbury, muffs were first used in the 1960s, but not on the total workforce. The MSA Mark IV ear muffs were introduced in all mines in 1973 because of hearing loss of miners observed from the audiometric program. Shortly after, in the same year, these ear muffs were exchanged with "NO NOISE" ear muffs, model NN3-F, made in Sweden, which featured foam-filled sealing rings (the Hellberg Standard Volume Hearing Protector). These ear muffs were still in use at the time of the study mainly because they are accepted by miners because of their low weight and comfort.

Over the last few years serious shortcomings of the "NO NOISE" ear muffs were becoming apparent. The main charge levelled against them was that their attenuation was poor under working conditions. Because an analysis of their effective attenuation had never been made at Falconbridge Mines, nor at any other Canadian mining operation, a joint project of Falconbridge[*], Mines Accident Prevention Association of Ontario (MAPAO), and Canada Centre for Mineral and Energy Technology (CANMET) was launched to carry out an evaluation. The following study parameters were decided:

— To measure the attenuation, comfort and clamping force of the "NO NOISE" ear muffs, model NN3-F, and compare this data with head size at four mines, Falconbridge, Strathcona, Fraser and Lockerby.

— To propose measures which would stabilize attenuation under working conditions.

Other types of ear muffs in use in small numbers were also examined.

The benefits of ear muff control fall under two categories:

— the benefits of reduced risk of hearing loss; and

— the benefits relating to a more comfortable working conditions.

Because of this, an ear muff control system for working conditions was developed.

Basic Conception

This project was started to establish attenuation of ear muffs under working conditions. Research was conducted under three different headings: manufacturer's attenuation data from clamping force and head size (bizygomatic diameter), and attenuation tests under working conditions (Fig. 1). The "real-ear" methods (and the "psychophysical" method) (CSA Z94.2-M1984 adapted ANSI S3.19-1974) measures the difference in the hearing threshold of the protected and unprotected subject and indicates the effectiveness of the hearing protector. Physical

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[*] Falconbridge Limited, Canadian Nickel Division, Sudbury Operations

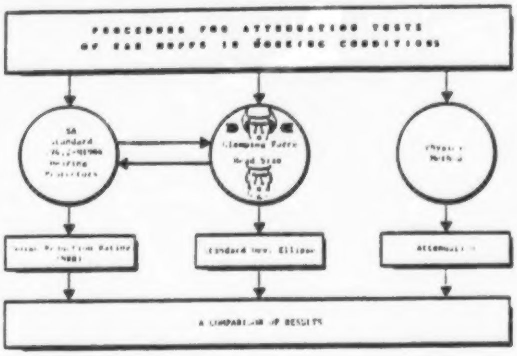

FIGURE 1. Flow sheet diagram of ear muff control in research procedures.

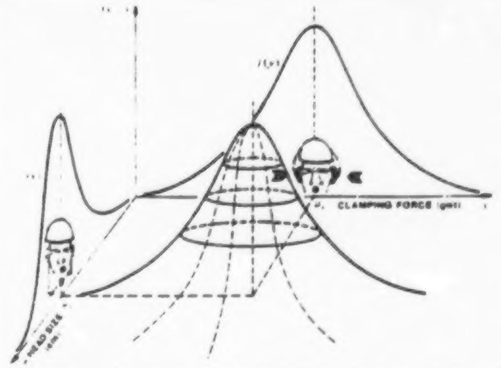

FIGURE 2. The two marginal density functions, head size and clamping force, are shown.

methods often involve two microphones, one outside the ear muff, and one between the cup and the subject's ear. The psychophysical method requires the use of a laboratory and the physical method is preferable for field evaluation of ear muffs. The measured ear muff attenuations were approximately the same in both methods at frequencies below 2000 Hz(1,2). Above 2000 Hz greater attenuation differences were measured in the psychophysical tests than in the physical tests (3.7 to 8.5 dB). The differences resulted from the inherent differences in the two test procedures.

The proposed control system is quick, simple and efficient. It does not interfere with the work a miner has to do yet it succeeds in controlling the attenuation expected of ear muffs under working conditions. It also obliges the safety department to maintain or exchange ear muffs frequently. The responsibility remains with the employee to ensure that ear muffs are properly fitted and worn. This responsibility will only be accepted by the employee when he/she is thoroughly trained in their deployment. Management can audit this protection in graphical form detailing the efficiency of ear muffs. This system is equally applicable in small and large mining operations, and it can be totally automated and computerized for even greater efficiency.

Standard and Regulation

The CSA Standard Z94.2-M1984, Hearing Protectors (Appendix A), recommends procedures for fitting, caring for, using, and implementing hearing protection programs. The sound attenuation test (ANSI S3.19-1974) requires the number of observations, e.g. 30, i.e. 10 subjects with three measurements each, at selected frequencies. The noise reduction rating (NRR) is defined as the difference between the over-all C-weighted sound level of a noise spectrum having equal energy per octave and the resulting A-weighted noise levels under a hearing protector.

The attenuation value used in calculating the NRR of a protector is the mean-attenuation value of the device measured in the laboratory minus two standard deviations (EPA* 40 CFR, Part 211). The NRR must be derated for users to allow for decreases in efficiency found in practice concerning the efficiency of hearing protection devices (HPDs). The problem is recognized by experts in the field, and deratings, such as subtracting 10 dB from the published NRR, have been proposed(3).

For the estimation of hearing protector adequacy, there are three basic methods. All methods used are based on factory-supplied data for brand new ear muffs, and may, or may not, be precise due to ear muff deterioration and fitting under working conditions.

Standard Deviation Ellipses (Standard Error Ellipses)

The standard ANSI S3.19-1974 is recommended for the measurement of clamping force, and uses hearing protectors separated to a distance of 14.35 cm between ear cups (medium head width = head size). Head size (bizygomatic diameter) influences the clamping force. Larger head size leads to a greater clamping force. Clamping force and attenuation are in a causal inverse relationship. Ear muffs sold on the market have gone through attenuation tests at a licensed laboratory. During the test (in triplicate) a suspension system presses the ear muffs against ten heads, thus yielding attenuation results which are based on 30 measurements.

The comparison method of two means in the case of paired observation may be applied to establish a relationship between: head size and clamping force. The two series of results of the observations are not independent because each results χ of the head size* is associated with a result y of the clamping force**. The head size and the clamping force are a direct causal relationship with attenuation***. The χ and y are then compared, to evaluate the effectiveness of the attenuation.

We shall now look at a joint distribution of two random variables—the bivariate normal distribution. This distribution is very useful when dealing with a planimetric (χ,y) position in our measurement.

The joint density function of two random variables X and Y which have a normal distribution(4-6) is:

$$f(x,y) = \frac{1-\rho^2}{2\pi\sigma_x\sigma_y\sqrt{1-\rho^2}}\exp\left\{\frac{-1}{2(1-\rho^2)}\left[\left(\frac{x-\mu_x}{\sigma_x}\right)^2 - 2\rho\left(\frac{x-\mu_x}{\sigma_x}\right)\left(\frac{y-\mu_y}{\sigma_y}\right) + \left(\frac{y-\mu_y}{\sigma_y}\right)^2\right]\right\} \quad \text{.......... (1)}$$

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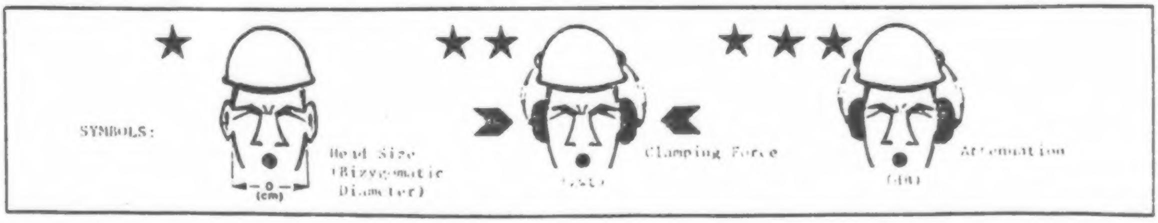
* The Environmental Protection Agency.



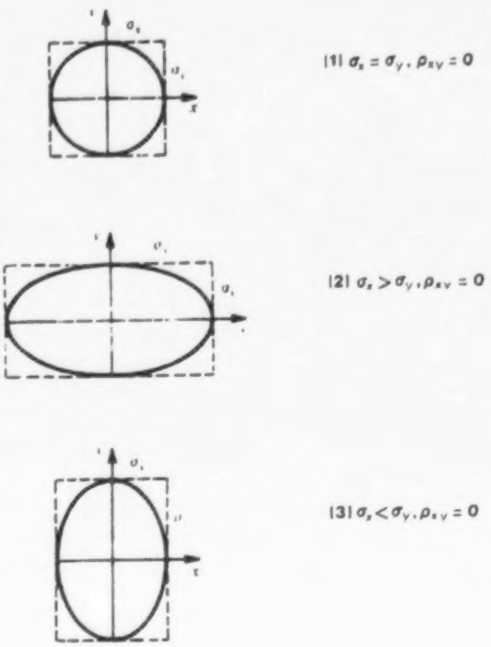
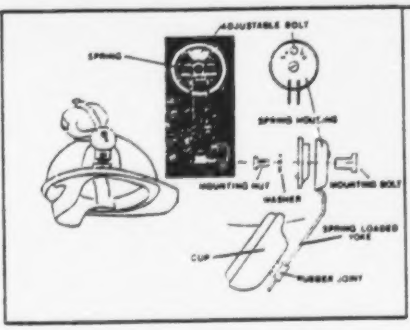

(1) $\sigma_x = \sigma_y, \rho_{xy} = 0$
(2) $\sigma_x > \sigma_y, \rho_{xy} = 0$
(3) $\sigma_x < \sigma_y, \rho_{xy} = 0$

FIGURE 3. Three different combinations of the standard deviation axes.



Sound Attenuation Data for the Hellberg Standard Volume Protector with Foam-Filled Seals. These measurements were made according to the American National Standards Institute (ANSI) Specifications S3.19-1974.

Test Frequencies in Hz	Brand Mean Attenuation in dB	Group	Group Attenuation in dB	Standard Deviations for 10 Sets of Measurements
125	16.2	[illegible]	[illegible]	[illegible]
250	19.9			1.8
500	[illegible]	3	[illegible]	[illegible]
1000	[illegible]			[illegible]
2000	[illegible]			[illegible]
3150	[illegible]			[illegible]
4000	[illegible]			[illegible]
6300	[illegible]		[illegible]	[illegible]
8000	[illegible]			[illegible]
EPA NRR [illegible]				

FIGURE 4. "NO NOISE" NN3-F muffs, Mark I new generation springs.

where, μ_x and σ_x are the mean and standard deviation of X; μ_y and σ_y are the mean and standard deviation of Y; and ρ is the correlation coefficient of X and Y as defined in statistics:

$$\rho_{xy} = \frac{\sigma_{xy}}{\sigma_x \sigma_y}$$

Since σ_x and σ_y are always positive, it can be shown that the absolute value of ρ_{xy} never exceeds unity, i.e.:

$$-1 \leq \rho_{xy} \leq 1$$

This density function has a bell-shaped surface over the x, y coordinate plane centred at $x = \mu_x$, $y = \mu_y$ (Fig. 2).

Two marginal density functions for X and Y are:

$$f(x) = \frac{1}{\sigma_x\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left(\frac{x-\mu_x}{\sigma_x}\right)^2\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$f(y) = \frac{1}{\sigma_y\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left(\frac{y-\mu_y}{\sigma_y}\right)^2\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

A plane that is parallel to the x,y corrdinate plane will cut the bivariate density surface in an ellipse. The equation for this ellipse is obtained by setting Equation 1 equal to the height K of the intersecting plane above x,y plane(4).

$$\left(\frac{x-\mu_x}{\sigma_x}\right)^2 - 2\rho\left(\frac{x-\mu_x}{\sigma_x}\right)\left(\frac{y-\mu_y}{\sigma_y}\right) + \left(\frac{y-\mu_y}{\sigma_y}\right)^2 = (1-\rho^2)c^2 \quad \ldots\ldots (4)$$

where $c^2 = \ln[4\pi^2K^2\sigma_x^2\sigma_y^2(1-\rho^2)]^{-1}$, a constant. Three examples illustrating the effects of different combinations in our case are shown in Figure 3.

The standard deviations σ_x and, σ_y are the semi-major axis and semi-minor axis, of vice versa.

The standard deviation of a sampling distribution of a statistic is often called its standard error. It is noted that if the sample size N is large enough, the sampling distribution is normal or nearly normal. These methods are known as large sampling methods. In practice it looks like the examples in Figures 8 and 9:

- In the coordinate system x—head size (cm), and y—clamping force (gwt), the corresponding values of mean and standard deviation of ear muffs are introduced. It is necessary to carry out 30 measurements of clamping force, using brand new ear muffs, for head sizes ranging from 13 cm to 15.5 cm (bizygomatic diameter).
- Head size and clamping force, for a minimum 30 sets of measurements, are measured in the field and entered into the coordination system. The larger the number of measurements the more representative the result.
- Mean and standard deviation of field measurements are calculated and an ellipse is constructed which clearly shows the standard deviation axes.
- Ear muff attenuation is determined and controlled by the position of the ellipse, more precisely: how the ellipse covers the plotted area of head size versus clamping force, and their mean and standard deviations for brand new muffs.
- The theoretical sampling distribution of the means are normally distributed; we can expect about 68% confidence in our results.

Control is simple and clear because the relationship between clamping force and attenuation is obvious(7).

Attenuation Measurements

Attenuation measurements are carried out using dosimeters both in the OSHA mode (5 dB doubling), and in the ISO mode (3 dB doubling or equal energy concept). Microphones were placed under the ear muffs on the left and right ear, on the collar, or on the brim of the hat, and connected to instruments assessing noise exposure. The exposures were timed with a stop watch, and at the end evaluations were made using graphical forms. The final results were tabulated and the mean and standard deviations were calculated.

TABLE 1. Sound attenuation data for the "NO NOISE" ear muff Mark I old generation springs (ANSI Z24.22-19501)

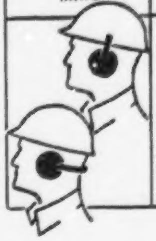
"NO NOISE" Ear Muff Band	Characteristic	Attenuation (dB)								
		Frequency - Hz								
		125	250	500	1k	2k	3k	4k	6k	8k
	Mean	11.5	16.5	26.5	36.5	38.0	38.5	44.5	39.5	-
	Std. Dev.	-	-	-	-	-	-	-	-	-
	Mean	13.4	17.3	28.6	41.8	40.7	45.2	42.7	32.6	29.3
	Std. Dev.	3.3	3.9	3.0	3.4	5.6	4.6	5.3	4.1	4.7

TABLE 2. Technical data of Mark I and Mark II springs of "NO NOISE" NN3-F muffs

Ear Muffs	N*	Diameter of Spring (mm)	Ultimate Load (N)	Tensile Strength (N/mm²)	Flexing Test (Cylinder (5 mm ⌀)
Mark I	3	2.013	4660	1484	6
Mark I	3	2.017	4660	1484	6
Mark II	3	2.000	6365	1390	7

* N = number of measurements

Measurement

It was clear to the author that efficient control of ear muffs in mines posed a complex and confusing problem. Before beginning the actual measurements, the author trained those who were to be wearing the measuring devices. These trainees varied greatly in terms of character, project worth and precision. During the actual measurements a three-pronged control was introduced: 1. with forms; 2. mutual control of wearers; and 3. supervisory control. Forms were constructed in such a way that each wearer was able to control himself during measurement taking. If the results were not good the measurements were repeated. The wearers worked alongside each other when possible and thus were able to control one another. They were given complete freedom in choosing measurement locations. Only in one mine were measurements done by a sole wearer. At all times, upon completing measurements, the wearers were asked to file a small report and make observations. The supervisor at each mine constantly controlled wearers' results and their over-all work.

Measurements of ear muff attenuation were made using noise dosimeters, types 4424 (ISO), and 4425 (OSHA), made by B and K, and the noise dosimeter with an integrating sound level meter, type db-307, made by Metrosonics. Noise dosimeters measure accumulated noise exposure and express it as a percentage of the maximum allowed daily exposure. The measurements were conducted for a period ranging from 12 to 30 minutes and longer (80 min) depending on the type of noise.

The Metrosonics type db-307 instrument measures sound over a continuous range of 45 to 130 dBA. Its microprocessor continuously samples and displays dBA sound levels while calculating L_{max}, L_{peak} and test duration. For each measurement two instruments were placed in a 'noise dosimeter' vest, which was developed at the Elliot Lake Laboratory.

The integrating sound level meter by B and K, type 2225 was used in areas (jobs) where assessment of the risk of hearing damage is important: A-weighting, L_{eq} for a fixed period of 60 seconds, RMS 'Fast' and 'Slow', plus 'Peak hold' response.

Measurements for the clamping force of ear muffs were performed with a manual balance and the assistance of both surveyors. Head sizes (bizygomatic diameter) were measured using specially adapted outside calipers.

The experimental protocol included the following:

— the miner is informed of the tests objectivity;

— the miner is asked to adjust his own ear muffs to his particular liking, and to make qualitative evaluations of comfort before and after the test;

— if a miner wishes to withdraw at any time or for any reason he may do so.

It was explained that all testing would be conducted with the full support of miners and supervisory personnel. In this way all possible negative and subjective influences on the final results were minimized as necessitated by the project's objective of accuracy.

Results

The results are presented under three headings:

1) Presentation of manufacturers' attenuation assessments (psychophysical method);

2) Field measurements of head size and clamping force;

3) Field measurements of ear muff attenuation (physical method).

The results of all measurements are tabulated and the final results are compared.

Manufacturers' Attenuation Data

Over ten years ago, the "NO NOISE" Hellberg Standard Volume Protector appeared on the Canadian market in two versions, either mounted on a hat, or on a head band. Attenuation characteristics were measured in accordance with the old ANSI standard (Table 1).

Both ear muffs in Table 1 are the same, having cup volume of 130 cm³. It is not clear why the cap-mounted ear muff has no standard deviation listed(8). For our project we branded this ear muff the "NO NOISE" Mark I Old Generation Springs.

Three years ago, a new ear muff, the "NO NOISE" NN3-F, was introduced similar to the old one (Fig. 4). However, the technical characteristics of this ear muff differed from those of the previous one, and its spring-loaded yoke was bent differently. Thus, we brand this ear muff the "NO NOISE" Mark I New Generation Springs. Both generations of springs were technically tested, and from the results in Table 2 it can be concluded that they are similar. Flexing tests show us that the spring wires are equally tempered.

Head Size and Clamping Force

Head size and clamping force measurements were carried out simultaneously by two surveyors to ensure less error. The condition of the ear muffs was also controlled. During each attenuation test the corresponding head size was also measured. The pairs of head size measurements agreed within the limits of error and gave essentially the same results 13.88 ≈ 13.82 cm, thus supporting the value of results obtained by each independent measurement and any conclusions arising from them (Table 3). The standard, ANSI S3.19-1974, which recommended the measurement of clamping force, used hearing protectors separated by a distance of 14.35 cm between ear cups (medium head width). However, our measurements showed a shorter average distance. Only at the Falconbridge Mine was the mean head size as large as 14.14 cm, with a markedly smaller head size of 13.64 cm at Fraser Mine. The author has examined the

TABLE 3. Head size and clamping force tests at Falconbridge Mines

No.	Mine	Head Size and Clamping Force Tests					Attenuation Tests		
		N_1+	Head Size D (cm)		Clamping Force (gwt)		N_2+	Head Size D (cm)	
			Mean	Std. Dev.	Mean	Std. Dev.		Mean	Std. Dev.
1	Falconbridge	34	14.14	0.54	990.44	322.22	46	13.91	0.65
2	Strathcona	93	13.92	0.77	1152.42	277.31	60	13.80	0.74
3	Fraser	57	13.64	0.77	1210.00	270.00	23	13.76	0.62
4	Lockerby	46	13.96	0.72	1313.59	261.23	18	13.64	0.33
	Total	230	13.88*	0.74	1175.27*	230.00	147	13.82*	0.66

Note. + Population (N_1 and N_2).
* Grand mean.

TABLE 4. Tests of ear muff conditions at Falconbridge Mines ("NO NOISE" NN3-F muffs)

No.	Mine	N*	Condition of Muffs					
			Good		Fair		Poor	
			N_1	Per cent	N_2	Per cent	N_3	Per cent
1	Falconbridge	34	23	67.65	8	23.53	3	8.82
2	Strathcona	93	71	76.34	14	15.05	8	8.60
3	Fraser	57	49	85.96	7	12.28	1	1.75
4	Lockerby	46	33	71.74	7	15.22	6	13.04
Σ	Total	230	176	76.52	36	15.65	18	7.83

Note. * Population ($N = N_1 + N_2 + N_3$).

surveyors' work closely and found nothing to suggest that the actual measurements obtained were biased. Measurements reflect differences in skull size among people of different origins; dolichocephalic skull mostly for those of English origin, and brachicephalic skull for those of central and east European origin.

The frequency curve for the head size measurements only (230 individuals) is shown in Figure 5. It indicates a slight skew to the left (negative skewness) with a hump at 13.25 cm head size. These humps occur where there are not enough intermediary skull shapes. Figure 6 shows the frequency curve of 147 subjects undergoing attenuation tests. Here there is also negative skewness with a hump at 12.5 cm head size because of the influence of dolichocephalic skulls. The frequency curves for both groups together of 377 individuals are shown in Figure 7. This general frequency curve reflects the skull development of the human species. Also, it should be noted that the size of the head generally depends on the height of the person(9). Furthermore, most experts now agree that skulls exhibit sexual dimorphism—the male of the species having an average skull size larger than those of the female. This should be considered in the design, adjustment, and fitting of ear muffs to a population.

In Table 3 one can see that clamping force was smallest at Falconbridge Mine, 990.44 (gwt), and largest at Lockerby Mine, 1313.59 (gwt). But when we compare sets of data which were measured independently, Falconbridge has a greater relative variation of 0.32, the other three mines at 0.20 to 0.24. We often need to known more than just the deviation; we need to relate the deviation to a meaningful base number, and that is the coefficient of variation.

From numerical data of head size and clamping force in Table 3, standard deviation ellipses were constructed for all mines (Figs. 8 and 9). Measurement data of all workers is also introduced. The average values for clamping force and head size (30 + 30) "NO NOISE" ear muffs, which were randomly selected from a group comprised of 30 muffs with Mark I Old Generation Springs and 30 with Mark I New Generation Springs are entered in the line graphs. Measurements were done using two hats: Head Guard Safe-T-Cap, and MSA Top Guard Hat, which are the hats most often worn in mines.

The "NO NOISE" muff, Mark I, Old Generation Springs had a strong clamping force, around 1550 (gwt), which caused discomfort. To cope with the discomfort, workers had a tendency to bend the spring loaded yoke, thus weakening the clamping force, even though there was an adjustable bolt on the spring housing (Fig. 4). In Figures 8 and 9 one can see that the clamping force for some workers was only 400 (gwt), which is much too low for good sealing and attenuation.

The standard deviation error ellipse for Falconbridge Mine is elongated in relation to the y-axis of clamping force (gwt). Only in small part does this ellipse cover the line curves plotted from measurements of brand new muffs (Fig. 8). From this data one can logically conclude that the clamping force was often low resulting in poor attenuation, and thus many ear muffs were not satisfactory. The springs were "damaged" and attenuation was poor. The proportion of satisfactory muffs were higher at the other Falconbridge mines. Figure 10 clarifies this point, and serves to make a comparison of ear muff attenuation (clamping force) between Falconbridge's four mines. No single ellipse completely covers another. On the basis of how well the ellipse covered the line curves, it is evident that Lockerby Mine had the best results. Fraser Mine, although it has a relatively small head size, also covers the plotted curve well.

Figure 11 contains a summary of all measurement data obtained at Falconbridge Limited. The standard deviation ellipse, calculated from the grand mean, shows that improvement needs to be made on the control of ear muffs in the working environment. It is obvious that clamping force increases with head size. However, there is a hiatus in this relationship when head size is 13.5 cm to 14.0 cm. In this range of head size 51 measurements were taken and confidence in the results is high. This result can be explained by the near absence of intermediary skull sizes, and is not due to workers bending the spring loaded yokes of their muffs. A difference of 170 (gwt) between head sizes 12.5 cm to 13.0 cm and 15.5 cm to 16.0 cm is enough to influence ear muff attenuation.

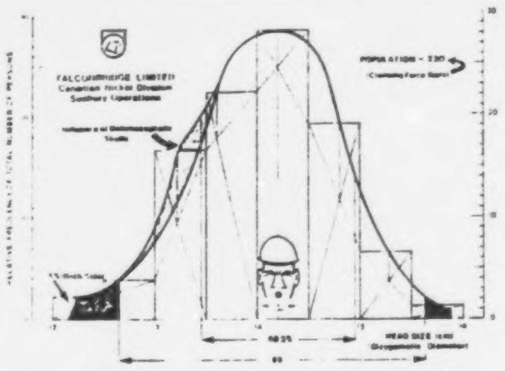


FIGURE 5. Frequency curve, slightly skewed to the left with a hump.

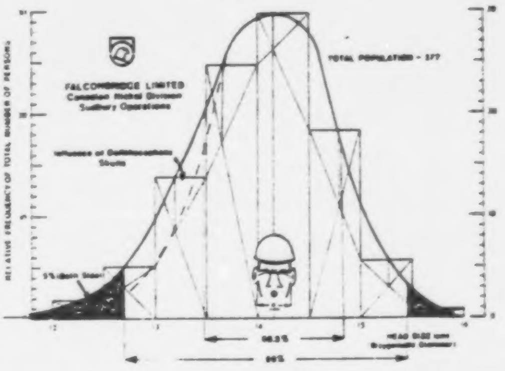


FIGURE 7. General frequency curve has the large tail of the distribution to the left, negative skewness.

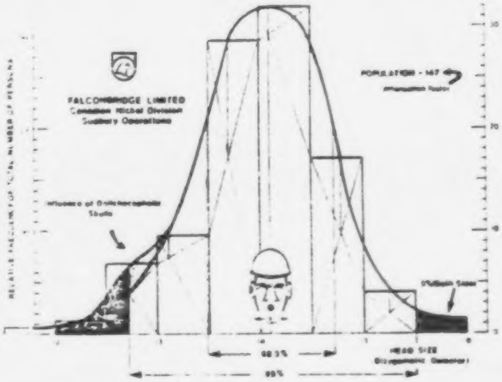


FIGURE 6. Frequency curve skewed to the left with a small hump.

During these measurements the condition of ear muffs was also checked (Table 4). In general, the condition of ear muffs in these mines requires closer attention. Only 76.5% of all ear muffs examined were in good shape, 15.5% were fair, while 8% were in poor shape. During the time, measurements were performed, muffs were repaired or replaced if necessary, a move which had a positive influence on the attenuation tests. In general, Fraser Mine's ear muffs were in the best shape.

Comfort

At the beginning of this report it was maintained that the "NO NOISE" ear muff found ready acceptance among miners because of its lightness and comfort. Alongside attenuation tests a test of comfort was also performed (Table 5). Comfort could be graded satisfactory, good or very good. Fifty-seven per cent of the workers thought "NO NOISE" ear muffs to be satisfactory, 38% good, and 5% very good.

The integrated ellipse surface in Figure 11 covers 62.5% of the area defined by head size versus clamping force of tested brand new muffs. If we consider that 57% rated the ear muffs only 'satisfactory', then it can be concluded that comfort and attenuation (clamping force) are mutually exclusive. Workers at the Falconbridge Mine rated ear muff comfort 65% good, and 4% very good. Looking at Figure 8, we observe that the error ellipse in large part lies outside the area of real efficiency of the "NO NOISE" NN3-F ear muffs. It is clear that a weaker clamping force has a positive effect on comfort. At the Strathcona and Fraser mines, with a total population sample of 75, not a single worker rated the "NO NOISE" ear muff as being very good. The same muff at Lockerby Mine, with a population sample of 23 was rated very good by 22%. Only at the latter mine is comfort not in an inverse relationship with clamping force, a relationship which might be explained by the small population.

The Noisefoe Mark IV ear muffs received a better over-all rating, 75% good, but the total population is small—28, and even smaller at particular mines, from 3 to 10. It is interesting to note that the Mark IV MSA muffs at the Lockerby Mine, with a population of 6, were rated only good.

From comfort data which were gathered during measurements, we can conclude that 57% of the workers were satisfied, while 43% were strongly in favour of the "NO NOISE" ear muffs. Analyses of comfort tests of eleven factory new ear muffs were conducted using 'Industrial Elimination' and Analyses of Variances (ANOVA)(10). "NO NOISE" ear muffs were chosen as being second best. For internal comparisons, the Newman - Keuls approach should be used(11).

Attenuation Test

Attenuation measurements at Falconbridge were taken in the OSHA and ISO modes (Table 6). The main measurements were taken using the "NO NOISE" muffs, which was the intention of this project. Secondary measurements were taken with the Noisefoe MSA Mark IV ear muffs. The results of attenuation measurements for the "NO NOISE" were almost identical in both the OSHA and ISO modes. Falconbridge Mine had the lowest attenuation, 10 dBA. The other mines had similar attenuation, varying between 12.5 and 13.0 dBA, which is 3 dBA better than Falconbridge's. This difference is large if one remembers that decibel scales are logarithmic.

The large sampling method (population is binomially distributed $N >> 30$) has shown that attenuation results are almost identical in both modes: 12.43 ± 6.15 dBA (OSHA) $\approx 12.49 \pm 5.23$ dBA (ISO). If we compare sets of data which are obtained separately, the coefficient of variation is 0.49 in the OSHA mode and 0.42 in the ISO mode. The OSHA mode shows slightly more relative variation.

Tests were also performed on the Noisefoe Mark IV ear muff, worn behind the head, using a small population ($N < 30$). The mean characteristics of the Mark IV are:

	Frequency (Hz)								
	125	250	500	1K	2K	3K	4K	6K	8K
Mean attenuation (dB)	17	18	29	36	38	44	44	43	43
Standard deviation (dB)	2.6	2.6	3.1	3.2	4.1	[illegible]	4.6	4.7	5.7

(Test in accordance with ANSI Z24.22-1957.)

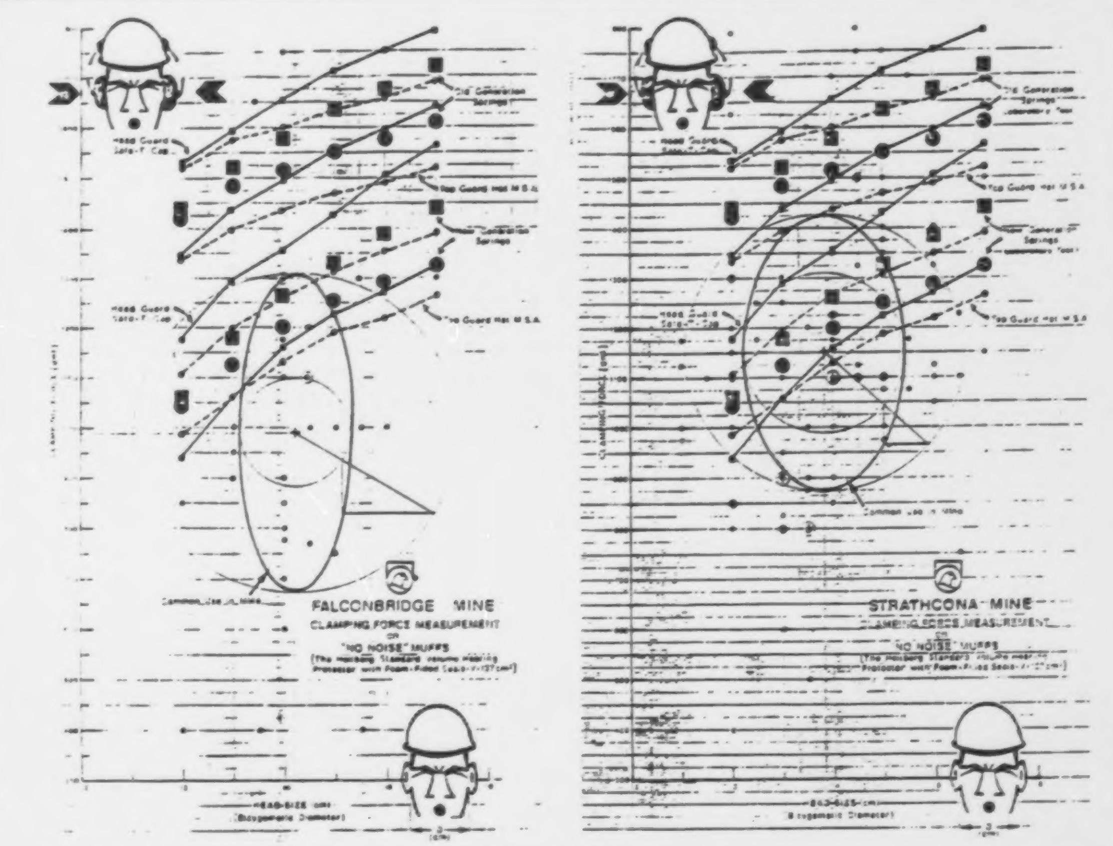


FIGURE 8. Standard deviation ellipses for Falconbridge Mine and Strathcona Mine.

TABLE 5. Comfort tests of ear muffs at Falconbridge Mines ("NO NOISE" muffs)

No.	Mine	N*	○-Satisfactory		◒-Good		●-Very Good	
			N_1	Percent	N_2	Percent	N_3	Percent
								"NO NOISE" NN3-F Muffs
1	Falconbridge	23	7	30.4	15	65.2	1	4.3
2	Strathcona	46	29	63.0	17	37.0	0	0.0
3	Fraser	29	22	75.9	7	24.1	0	0.0
4	Lockerby	23	11	47.8	7	30.4	5	21.7
Σ	Total	121	69	57.0	46	38.0	6	5.0
								Mark IV Muffs
1	Falconbridge	9	2	22.2	7	77.8	0	0.0
2	Strathcona	10	3	30.0	7	70.0	0	0.0
3	Fraser	3	2	66.7	1	33.3	0	0.0
4	Lockerby	6	0	0.0	6	100.0	0	0.0
Σ	Total	28	7	25.0	21	75.0	0	0.0

Note:* Population ($N = N_1 + N_2 + N_3$).

The attenuation measurements in the working environment were as good as those done for "NO NOISE" muffs. In the OSHA mode the result is lower by 1.33 dBA than the result in the ISO mode: 12.96 ± 6.35 dBA (OSHA) < 14.29 ± 6.67 dBA (ISO). The coefficients of variance are 0.49 (OSHA) and 0.47 (ISO). We now know that there is no variation with respect to the two modes. Comparisons that use the standard deviation in relation to the average are more informative than the standard deviation alone. We often need to know more than just the deviation. We need to relate the deviation to a meaningful base number, and that is what the coefficient of variation does. From these measurements it can be concluded that the Mark IV muffs provide an insignificantly better attenuation by 1.26 dBA when the results are averaged in OSHA and ISO modes.

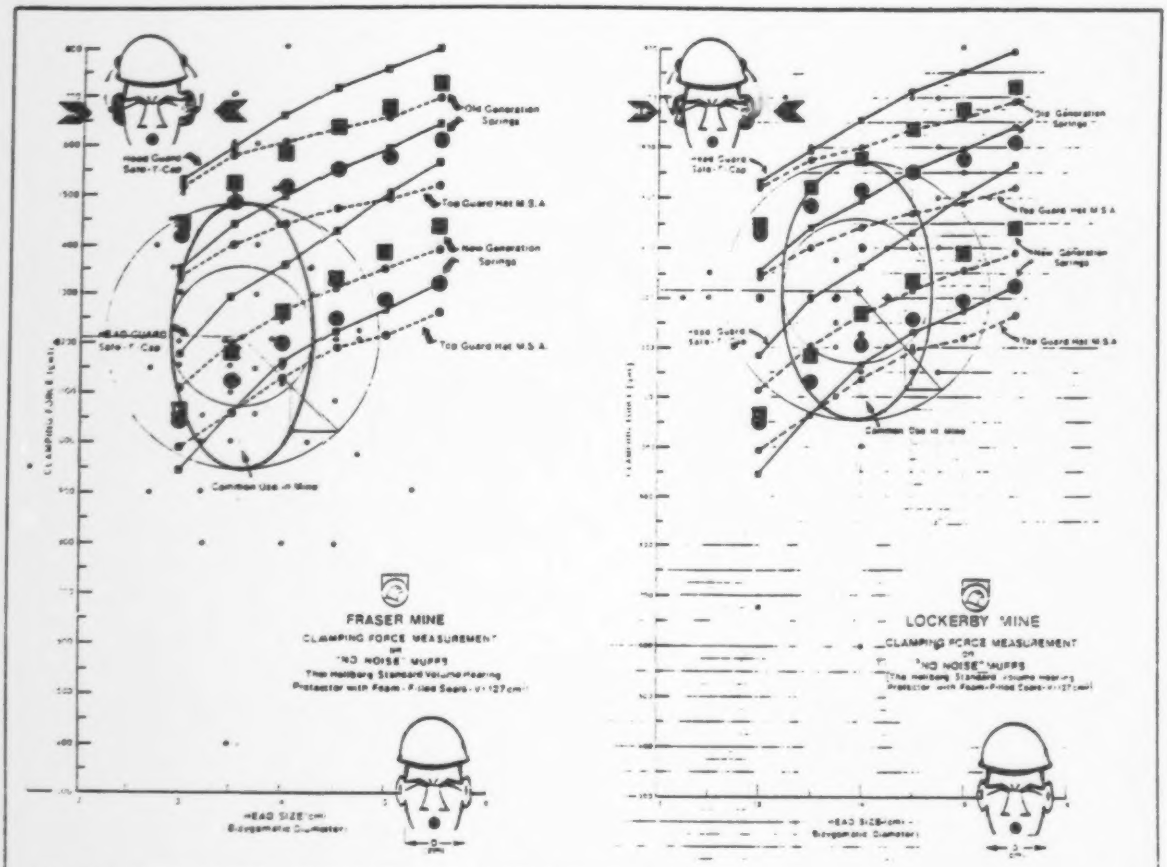


FIGURE 9. Standard deviation ellipses for Fraser Mine and Lockerby Mine.

On the basis of measurements taken at all four Falconbridge mines, bar graphs for OSHA and ISO modes were constructed to show the influence of head size on attenuation of "NO NOISE" ear muffs (Fig. 12). The population here is smaller than the one declared in Table 5 because surveyors were not always able to measure head size. From 90 attenuation measurements in the OSHA mode, 60 head sizes were measured; and, from 105 attentuation measurements in the ISO mode, 66 head sizes were measured. Still, the populations are large enough to make certain conclusions from them.. From OSHA and ISO bar graphs, for head sizes smaller than 12.5 cm and larger than 15.0 cm we can make no conclusions because there were too few of them in the population. For head sizes from 12.5 cm to 15.0 cm attenuation varies irregularly, which proves that clamping force itself varies irregularly from case to case. If we now look at Figures 8 and 9, we observe that clamping force varies markedly in this range, in which the greatest population is found. This is yet another proof that attenuation is strongly related to clamping force.

Comparison of Results

The attenuation of "NO NOISE" ear muffs was analyzed under three headings (Fig. 1):

1. Analysis of attenuation characteristics in manufacturer's data and their accordance with the standard.
2. Analysis of the relationship between attenuation and head size/clamping force.
3. Attenuation measurements under environmental conditions.

Measurements were carried out with good accuracy and any possibilities of bias were eliminated. The error ellipse of Falconbridge Mine poorly covers head size versus clamping force curves. Attenuations of its ear muffs are: OSHA mode, 9.92 ± 5.57 dBA, and ISO mode, 10.19 ± 4.11 dBA. Error ellipses from the other mines cover head size versus clamping force curves better, and their attenuations are better:

Mine	OSHA Mode	ISO Mode
Strathcona	12.97 ± 5.76 dBA	13.10 ± 6.38 dBA
Fraser	12.68 ± 6.82 dBA	13.29 ± 4.83 dBA
Lockerby	12.86 ± 5.86 dBA	12.02 ± 4.30 dBA

Grand Means for all Falconbridge mines are:

OSHA mode 12.43 ± 6.15 dBA
ISO mode 12.49 ± 5.23 dBA

These results are in accordance with the error ellipse from summary data (Fig. 11). When the ellipse fully covers the head size/clamping force curve, attenuation is then 14 dBA or more. This system, developed at the Elliot Lake Laboratory, has further implications in practical and theoretical fields, as well as in the formulation of standards.

From the formula for calculating ear muff efficiency:

$$dBA = dBC - (NRR-10),$$

it is clear that efficiency depends on the frequency range of the noise source. On average, the dBC is greater than dBA in mines by 2 to 3 dBA, which would fall within Falconbridge's grand mean of 12.5 dBA.

Conclusions

Noise pollution has been recognized as a hazard and a problem in Canadian mines and mills. The high cost of fully implement-

TABLE 6. Attenuation of ear muffs at the Falconbridge Mine in OSHA mode and ISO mode ("NO NOISE" muffs)

"NO NOISE" MUFFS

No.	Mine	Character	OSHA - Dosimeter				ISO - Dosimeter				OSHA(B.S) Minus ISO(B.S)
			Level+ (dBA)	Attenuation (dBA)			Level+ (dBA)	Attenuation (dBA)			
				L.S.*	R.S.*	B.S.*		L.S.*	R.S.*	B.S.*	
1	Falconbridge	Mean Std. Dev.	99.02 7.67	8.00 6.47	10.60 6.18	9.92 5.57	102.49 9.53	11.14 5.53	9.23 5.80	10.19 4.11	-0.77
2	Strathcona	Mean Std. Dev.	107.38 8.93	13.40 6.47	11.83 6.27	12.97 5.76	109.11 8.97	12.62 7.17	13.68 7.39	13.10 6.38	-0.13
3	Fraser	Mean Std. Dev.	104.11 6.12	14.04 7.71	11.24 7.43	12.68 6.82	104.60 7.24	13.43 4.68	13.22 6.03	13.29 4.83	-0.61
4	Lockerby	Mean Std. Dev.	107.90 7.36	12.84 7.56	12.92 6.43	12.86 5.86	106.06 8.02	12.11 4.08	11.97 6.33	12.02 4.30	+0.84
Σ	Total	Grand Mean Std. Dev.	104.81 8.41	12.84 7.36	11.62 6.58	12.43 6.15	105.98 8.79	12.46 5.59	12.45 6.73	12.49 5.23	-0.06
Population			90	72	72	70	105	91	92	87	

Note: + Level during test time.
* L.S. - Left side; R.S. - Right side; B.S. - Both sides.

MARK IV MUFF

No.	Mine	Character	OSHA - Dosimeter				ISO - Dosimeter				OSHA(B.S) Minus ISO(B.S.)
			Level+ (dBA)	Attenuation (dBA)			Level+ (dBA)	Attenuation (dBA)			
				L.S.*	R.S.*	B.S.*		L.S.*	R.S.*	B.S.*	
1	Falconbridge**	Mean Std. Dev.	93.98 3.15	- -	- -	- -	93.5 3.6	9.67 8.58	6.95 3.25	- -	-
2	Strathcona	Mean Std. Dev.	107.50 10.47	18.00 6.13	11.30 6.82	13.20 5.13	112.65 10.14	17.84 5.76	18.56 7.22	18.22 4.54	-5.02
3	Fraser	Mean Std. Dev.	107.35 5.22	17.60 5.05	17.37 6.44	17.47 5.71	107.73 6.79	14.43 4.73	15.13 5.53	14.73 5.12	+2.74
4	Lockerby	Mean Std. Dev.	106.70 5.85	9.30 7.90	11.83 6.81	10.55 6.99	107.27 2.45	9.90 5.18	7.97 8.35	8.91 6.34	+1.64
Σ	Total	Grand Mean Std. Dev.	107.17 7.69	14.44 7.63	12.83 6.68	12.96 6.35	111.19 7.31	14.38 6.32	14.14 8.48	14.29 6.67	-1.33
Population			16	15	14	13	19	19	19	19	

Note: + Level during test time.
* L.S. - Left side; R.S. - Right side; B.S. - Both sides.
** In Grand Mean value not included.

ing a 90 dBA noise standard requires that we develop inexpensive, yet effective, methods to attenuate noise in mines. In this transition period from hearing protectors to a full reduction of noise at source, we must accept the near permanency of ear muffs and plugs as a way of saving workers' hearing. Manufacturers of hearing protectors claim their products offer reductions of 23 decibels (NRR) or more, but they fail to point out that this reduction is obtainable only under ideal conditions. The reality of attenuation under working conditions, as several studies have found, is quite different.

In our study we investigated the "NO NOISE" ear muffs model NN3-F, a Swedish product, with foam-filled sealing rings (the Hellberg Standard Volumes Hearing Protector), which was used extensively at Falconbridge Mines in Sudbury.

Methods for using short measurements to determine the noise exposure index, and for controlling muff-wearing habits, were developed at the Elliot Lake Laboratory. Measurements taken at Falconbridge on "NO NOISE" ear muffs revealed that they have a practical attenuation of some 10 to 13 decibels. It is important to note here that measurements also revealed that clamping force (thus attenuation) was in an inverse relationship with ear muff comfort. Measuring attenuation using noise dosimeters was a difficult job. Not a single surveyor would be completely satisfied with these measurements (physical method). Apart from that, it was impossible to measure, in one shift, more than two work stations, due to instruments breaking down, the distance between work stations, short work cycles, and other factors. Because of this, we sought a solution: measuring head size and clamping force in relation to attenuations which are measured by certified laboratories, for brand new muffs before they reach the market.

A detailed analysis of the relationship between attenuation and head size/clamping force was done at four mines. Construction of standard deviation ellipses (standard error ellipses) for head size versus clamping force are in close agreement with measurements that were carried out. In order to measure clamping force an apparatus was constructed and a method for measuring suspension system durability was described in this report. At the same time we sought to slow down deterioration of ear muffs in mines as well as to put in place a system whereby attenuation can be controlled and improved. The clamping force apparatus, can be easily operated, and all data obtained can be fed into a computer, thus providing quick and exact information. This control system is a new step in studying ear

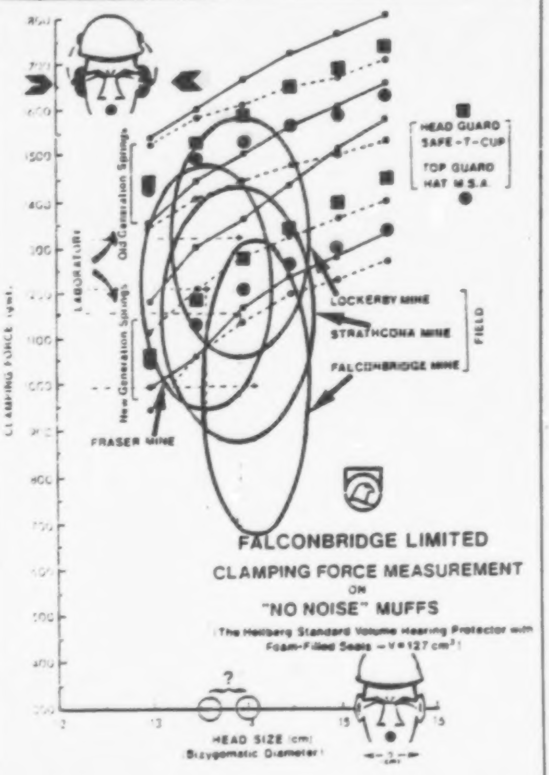


FIGURE 10. Standard deviation (error) ellipses in four mines.

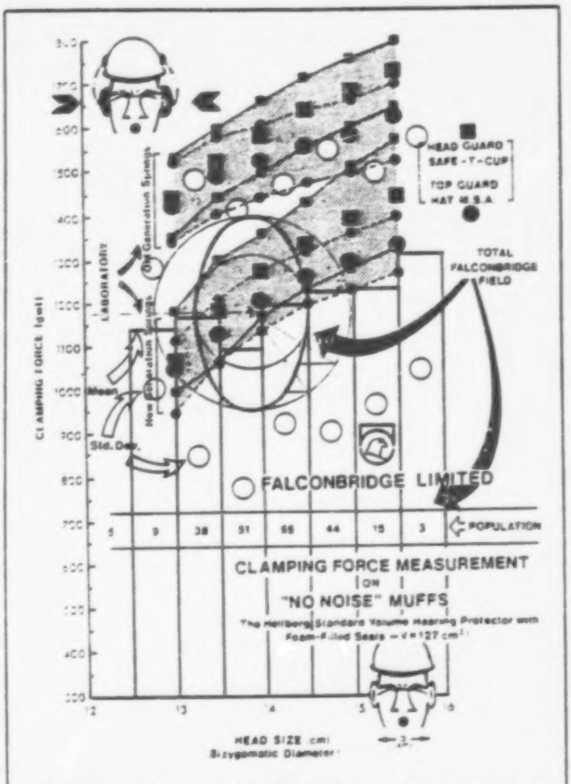


FIGURE 11. Summary data for head size and clamping force measurements at Falconbridge Limited.

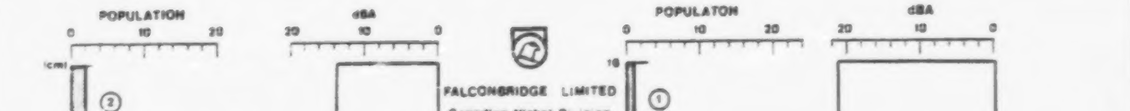


FIGURE 12. Relationships between head size and attenuation during measurements at Falconbridge Mine.

muff efficiency in working environments.

From these measurements it can be concluded that ear muffs in themselves are not a total solution to noise attenuation. Ear muff control should be continued, by measuring head size and clamping force with the clamping force apparatus.

Acknowledgments

The authors wish to acknowledge the help and cooperation of E. Isaacs, director, and P. Savalas, field technician, MAPAO, as well as senior mines supervisor, L.H. Rajala, N.A. Girard of Falconbridge East Mine, D.J. Cornett, Strathcona Mine, J.A. Riddell, Fraser Mine, T. Lakanen, Lockerby Mine, and Dr. A.G. Cecutti, medical director, D. McPhee and R. Desjardins, technicians, J. Dwyer and L. Montpellier, Safety Department of Falconbridge Ltd., Falconbridge, Ontario.

Acknowledgment is also extended to J. Vergunst, working environment engineer, Ontario Ministry of Labour, Sudbury, and R. Pleasance, branch manager, Levitt-Safety Ltd. (Metrosonics Ltd.), Sudbury, Ontario for the loan of the instruments.

Thanks also go to G. Knight, research scientist, Elliot Lake Laboratory for reviewing the manuscript and making numerous helpful suggestions.

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Appendix A—Peak Levels Measurement

Apart from just noise levels which were measured during attenuation tests, L_{max} and L_{peak} were also measured (Fig. A-1). The purpose of these measurements was to find differences between sound pressure levels in dBA, and peak levels (impulse or impact noise), and to find an explanation for the hearing loss which occurs in different mine occupations at 4 to 6 kHz[12]. Impulse or impact noise is defined as a sound which reaches peak intensity within a rise time of not more than 30 milliseconds, and which has a duration of not more than 500 milliseconds. The results in Figure A-1 were obtained using a B and K Integrating Sound Level Meter Type 2225 with 'Slow' and 'Fast' time constants, and a 'Peak Hold' better than ± 01 dB/s with a 30 µs rise time. The most interesting aspect of these measurements is to find out how large the 'Peak' value is above L_{max}. The larger the difference, the more hazardous the noise. At the base of the pyramid is the underground jaw crusher, and at the top is the tertiary crusher. All the machines which produce clatter (e.g. scooptram) are found between the underground jaw crusher and the secondary crusher and those which function properly are found between the secondary and tertiary crushers. Despite the fact that machines were in constant movement, causing instrument readings to constantly move as well, measurements were performed with good accuracy. Means and standard deviations of L_{max} and L_{peak} standard deviations are:

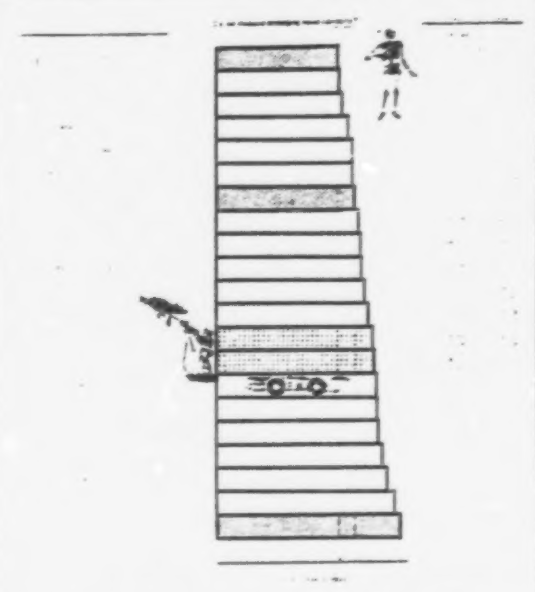


FIGURE A-1. The pyramid of peaks in mining and milling operations at Falconbridge Mines.

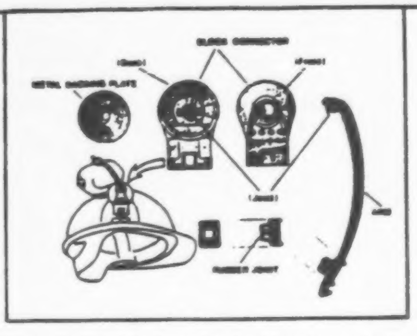
	Standard Deviation		
Characteristics	L_{max}	L_{peak}	**Population**
Mean	4.51	5.00	19
Standard Dev.	3.45	3.04	19
Confidence 99% (T-test)	4.51 ± 2.33	5.00 ± 2.01	19
Confidence 95% (T-test)	4.51 ± 1.66	5.00 ± 1.47	19

A discrepancy of 0.5 dB can be overlooked because the instrument is precise to ± 1 dB. However, this cannot be said of the db-307 Noise Dosimeter and Integrating Sound Level Meter made by Metrosonics. Discrepancies of the magnitude of 7 dB for the same types of measurements under similar conditions are not acceptable. This most likely occurred because of the slow processing speed of the CMOS chip. This microprocessor controls all computer functions while simultaneously calculating the desired operations. Metrosonics claims that "all" processing cycles have sufficient speed which is not true[13]. The CMOS chip provides good results only at average sound pressure levels.

Appendix B—Suspension System Durability

Tests indicate that the measured attenuation (noise reduction obtained when the workers fit the ear muffs themselves) is substantially less than the manufacturers' claimed attenuation. The Institute of Occupational Medicine (IOM) has carried out extensive research for the National Coal Board and the European Community on hearing protectors and has found that a typical muff, after three months use in a mine, provides only a quarter of the protection of a new muff[14]. This was so largely because of a reduction in clamping force.

For this reason mine management decided, while measurements were being taken, to replace the "NO NOISE" muffs with a new generation of Hellberg's muffs, the Mark V large-volume hearing protectors with foam-filled seals (Fig. B-1). Their cup volume is 203 cm³, and they have a NRR factor of 27 dB. The tension spring of the hard hat attachment is not made of metal; the arm is also made of non-metallic materials. Therefore, the arm cannot be so easily bent; and any attempt to do so would in fact cause it to break under excessive pressure, thus rendering the muff useless.



Sound Attenuation Data for the Hellberg MV Large Volume Hearing Protectors with Foam-Filled Seals. These measurements were made according to the American National Standards (ANSI) Specifications S3.19-1974.

Test Frequencies in Hz	[illegible] Attenuation in dB	Group	Group Attenuation in dB	Standard Deviations for 10 Sets of Measurements
125 250	[illegible] 29.9	A	48.1	1.5 1.6
500 1000 2000 3150 4000	31.6 36.8 38.8 40.0 42.8	B	189.3	2.6 1.8 2.3 2.2 2.9
6300 8000	43.1 40.6	C	83.7	4.0 3.3

EPA NRR factor = 27 dB.

FIGURE B-1. New generation of Hellberg's muffs: the Mark V, large-volume hearing protector.

The suspension system durability test was developed at the Elliot Lake Laboratory in accordance with a Canadian Standard[15]. The power source used to flex the ear muffs was a 66 cm Standard Crank Shaper manufactured by Canada Machinery Corporation of Cambridge, Ontario, the Hellberg Mark V ear muff was tested (Fig. B-2). Stroke length of the muff was adjusted to 8.25 cm. This stroke length approximates the distance an ear muff is moved from its position on the wearer's ear to its resting place on the hard hat. The number of strokes of the muff was recorded using a small counter attached to a magnetic base indicator holder. For each recorded count the ear muff moved through one inner and one outer stroke. The hard hat was fastened to a sheet of plywood (30 cm x 35 cm), which in turn was attached to the side of the shaper table. The ram head tool holder had a paddle-shaped board attached to it which was positioned against the inner cushion of the ear muff.

No failures were found in testing to 15 000 cycles of three units. The Canadian Standard called for 2500 cycles. The first test was conducted with 10 000 cycles at 17 per minute, and 5000 at 25 cycles per minute. The other two tests were run at 15 000 cycles at 25 per minute. This frequency was higher than recommended in the Candian Standard, 12 cycles/min, but this change would be expected to lead to more rapid failure. Assuming a worker removes the ear muffs between 20 to 30 times per shift the muffs should last a minimum of two to three years. Since the clamping force pressure is not adjustable on the Mark V ear muffs, the result is a more constant clamping force.

Appendix C—Clamping Force Apparatus

The clamping force apparatus was designed to prevent deterioration of ear muffs in mines (Fig. C-1). By measuring head size (bizygomatic diameter) and clamping force, attenuation data can

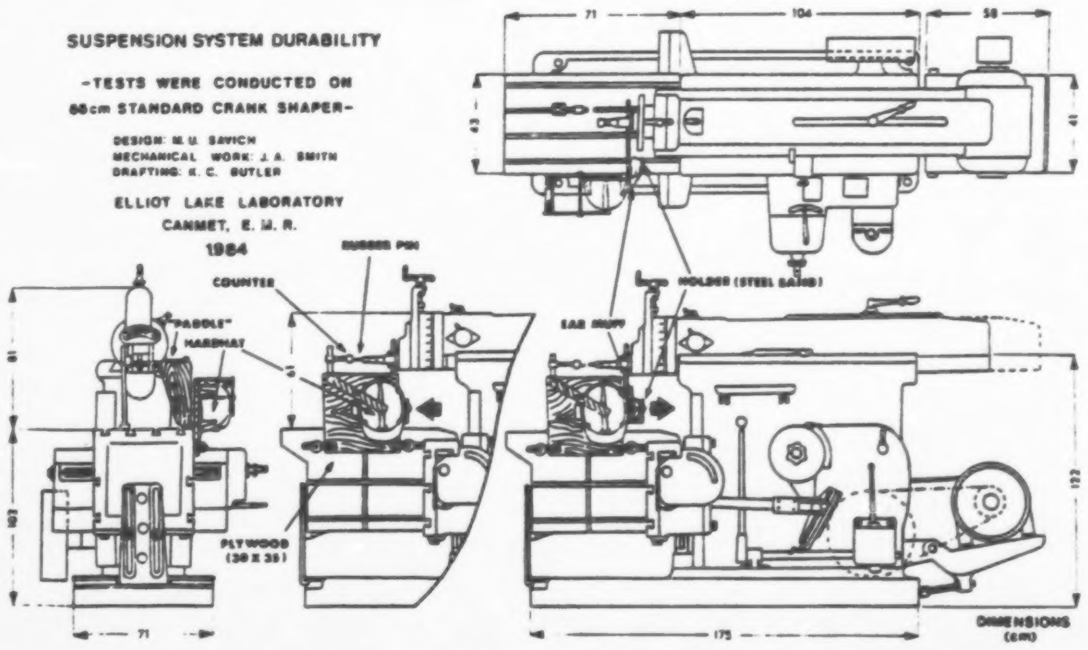


FIGURE B-2. Suspension system durability tests were conducted on a 66 cm Standard Crank Shaper manufactured by Canada Machinery Corporation, Cambridge, Ontario.

be obtained indirectly according to the procedure outlined in this report.

The basic characteristics of the clamping force apparatus are:

1) The centreline passes through the pivot point of ear cup attachment of head band or hard hat.

2) Head size is obtained with calipers by measuring the distance with a ruler; clamping force is measured by sliding a weight along a scale to the corresponding head size.

3) Construction: any material can be used providing the units are made rigid. However, the basic plate must be made of plexiglass so as to be able to see the scale (plate) and weight.

4) Calibration is made by using a manual balance which in turn measures clamping force as the weight is slid along a steeply sloping plate. A scale relating to the manual balance is made on the plate.

5) Operation: the ear muff to be measured is positioned so that the points of attachment of the head band or hard hat to the ear cups are located at the centreline marks of a worker in vertical position. The force is read from the scale on the steeply sloping plate in grams (gwt).

6) Accuracy: measurement accuracy is estimated after the clamping force apparatus is constructed, on 10 different ear muffs by three different persons.

With the clamping force apparatus it is possible to measure every kind of ear cup. Improvement of its construction, however, is desirable and any suggestion would be welcome. This apparatus can be operated automatically and all data obtained can be stored in a computer. After measurements are completed the computer provides all necessary information gained from the data: head size versus clamping force is plotted on a cartesian plane; worker's record mean and standard deviations; error ellipse, etc. All is done to maximize result accuracy and to eliminate bias.

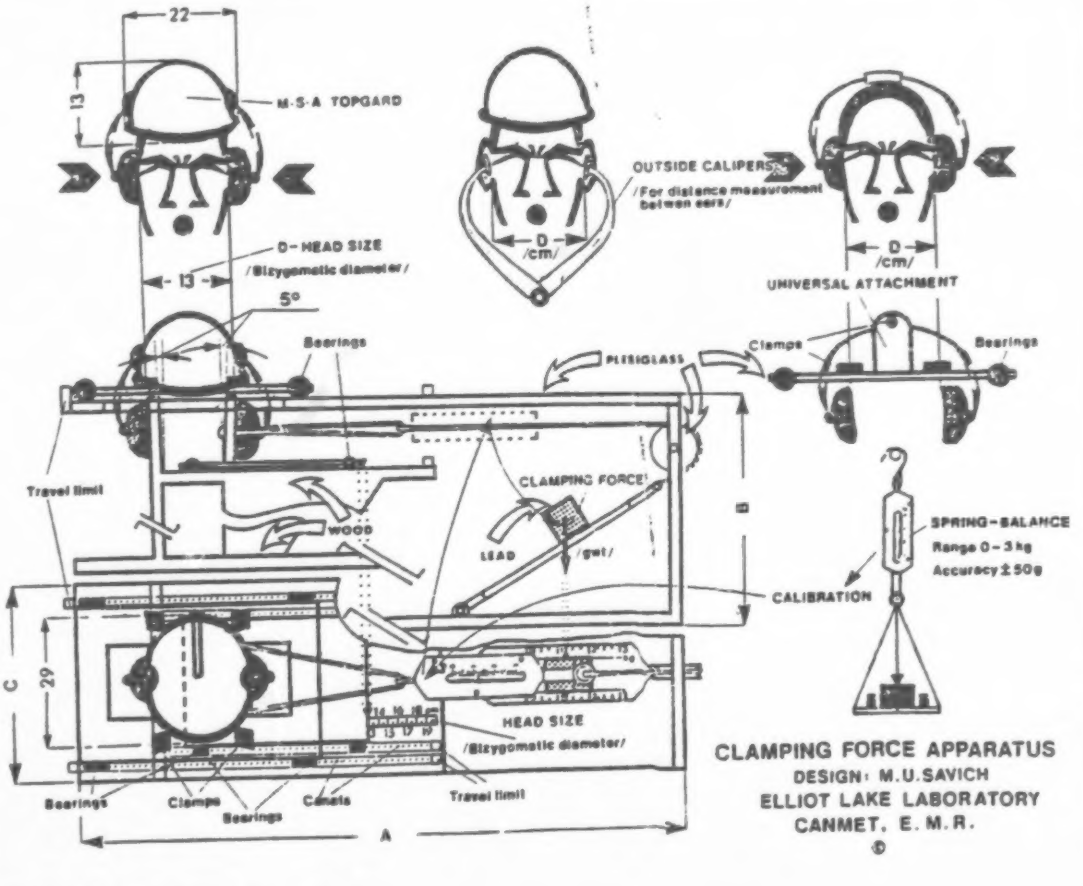

22
13
M-S-A TOPGARD
OUTSIDE CALIPERS
/For distance measurement between ears/
D
/cm/
D-HEAD SIZE
/Bizygomatic diameter/
13
5°
UNIVERSAL ATTACHMENT
Bearings
PLEXIGLASS
Clamps
Bearings
Travel limit
CLAMPING FORCE
WOOD
LEAD
/gwt/
B
SPRING-BALANCE
Range 0 – 3 kg
Accuracy ± 50 g
CALIBRATION
C
29
14 16 18 cm
13 15 17 19
HEAD SIZE
/Bizygomatic diameter/
Bearings
Clamps
Bearings
Canals
Travel limit
A
CLAMPING FORCE APPARATUS
DESIGN: M.U.SAVICH
ELLIOT LAKE LABORATORY
CANMET, E. M. R.
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FIGURE C-1. Clamping force apparatus.

Resnik Challenger Medal established

A new Medal in honor of the late Dr. Judith A. Resnik, NASA Mission Specialist and a member of the Society of Women Engineers, was established on June 1, 1986.

The medal, the Resnik Challenger Medal, will be awarded to a woman engineer for her visionary contributions to space exploration.

The entire engineering community, including technical societies, engineering industries, academia, or individual engineers, can nominate qualified candidates for the medal.

The Society is also developing a Resnik scholarship. For more information, contact: Headquarters, Society of Women Engineers, 345 E 47th St. New York, N.Y. 10017, U.S.A.